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(54) **Sectorized multi-function cellular radio communication system**

(57) A communications system (10A, 10B) comprises cells (11), each cell comprising a substantially centrally-located receiving and/or transmitting antenna member surrounded by a plurality of substantially sector-shaped regions (12, 14, 38, 40) extending out to the edge of the cell from the antenna member, the antenna member comprising a plurality of circumferentially distributed directional antenna elements (15A, 17A, 15B, 17B), each antenna element being arranged to communicate only with receivers (20, 22, 28, 30) located within a single one of said sector-shaped regions, the sector angles of the sector-shaped regions (12, 14, 38, 40) lying within the range 2 degrees to 15 degrees.

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Description

DESCRIPTION OF THE INVENTION

5 TECHNICAL FIELD

[0001] The present invention relates to the field of communication systems. More particularly, this invention comprises an extension of the telephone communications network or a stand-alone communications system which is capable of providing two-way broadband links, selectable video-on-demand, wireless cable services and enhanced audio programming.

BACKGROUND ART

[0002] In recent years, the demand for communications capacity has increased dramatically. Governments, businesses and individuals produce prodigious quantities of information at ever increasing rates, and also stoke the demand for high speed transfers of data, voice and video signals. More powerful personal computers and software are now able to create large database, real-time video, graphics and multimedia files. While our ability to generate information has skyrocketed, our ability to distribute and exchange this information is limited by the embedded narrow band infrastructure of the existing local telephone systems. Although the world is wired with over a billion miles of copper and has tens of millions of miles of installed optical fiber, this network is severely constrained by the bottleneck which resides at the interface between the local telephone company and its customers' premises, i.e., the "last mile". The gradual addition of more optical fibers and the implementation of various compression technologies can ameliorate this critical fault in the existing communications environment, but ultimately at great cost and on a schedule which will require several decades for completion.

[0003] Several attempts to solve the problem of distributing information to large numbers of subscribers have met with mixed results.

[0004] U.S. Patent No. 2,288,802 issued to John Hays Hammond in 1942 and entitled *Signaling System* discloses a radio transmission system which employs a carrier wave that is transmitted in two substantially independent channels. The channels are "made independent" by using polarizations which propagate at right angles to each other. The carrier waves may also be modulated "by the same signal frequency, but with a predetermined phase relationship between the two modulations." See Hammond, Column 1, Lines 1-24.

[0005] U.S. Patent No. 4,747,160, issued to Bernard Bossard on May 24, 1988 and entitled *Low Power Multi-Function Cellular Television System* describes a network of low power, substantially omni-directional cell node transmitters which communicate with a directional receiving antennas. Bossard's omni-directional transmitter imposes severe constraints on the ability of this system to provide diverse information services to many different customers.

[0006] One particular disadvantage of Bossard's system, which is due to its omni-directional signal, is the limitation of the system to compensate for rainfall in small portions of customer cells. Since the entire signal must be amplified at an omni-directional broadcast node, the system runs the risk of overpowering the signal to customers which are unaffected by the stormfronts. Bossard compensates for this constraint by limiting cell size.

[0007] Another severe limitation of the Bossard invention is the inability of the Bossard system to transmit to a single customer, or to transmit different signals to many different customers. The cell size in Bossard's system is also limited to the amount of power generated, which is dependent on the available (TWT) of about 100 watts. The base case for Bossard's system might be a quadratic cell for a "substantially" omni-directional system, in which a 100 watt TWT might be located in each of four quadrants of a broadcast cell, limiting the cell broadcast power to approximately 400 watts.

[0008] In 1977, Xerox Corporation initiated work on the *Xerox Telecommunications Network (XTEN)*, a nationwide, high-speed, end-to-end, digital communications service. XTEN was designed to provide local data services using a combination of substantially omni-directional transmission from cell nodes and point-to-point return links from transceivers located at business premises. Local networks were to be connected by intercity satellite or terrestrial "backbone" facilities. See *Xerox Petition for Rulemaking*, filed with the Federal Communications Commission on 16 November 1978. See also *Xerox Comments on the DTS Notice of Proposed Rulemaking*, filed with the Federal Communications Commission on 14 January 1980.

[0009] Siemens A.G. applied for U.K. Patent No. 1,586,260 in 1977. This patent, entitled *A Radio Telecommunications System*, discusses a system which connects stationary subscriber stations to a telecommunications network such as a public telephone network. A radio concentrator, assigned to a dial-operated exchange, is connected to the stationary subscribers via an omni-directional antenna. See Siemens '260, Column 1, Lines 9-13 and Lines 21-24.

[0010] Siemens was also awarded French Patent No. 1,024,523 entitled *Réseau d'émetteurs d'ondes Ultra-courtes*, which also pertains to transmission of radio and television programs. See Siemens '523, *Resumé*, Column 4.

[0011] In June of 1982, George Jacobs published a paper entitled Low Power Television in IEEE Spectrum. Jacobs explains the impact of the development of short-range, low-cost television systems. Figure 3 of his article reveals the components of a low-power television station designed to produce electromagnetic power of a kilowatt or less.

[0012] Donald Silverman offers an analysis of an integrated, end-to-end digital communications service which may be used to augment existing inter-city network facilities in his paper entitled The Digital Termination System Solution for High Speed Local Distribution. This paper was published in the January, 1983 edition of Microwave Journal.

[0013] The IEEE Spectrum published a paper in June, 1983 by George Cooper and Ray Nettleton entitled Cellular Mobile Technology. The Great Multiplier. This article discusses the advantages of a cellular mobile communications system, interference problems, narrowband modulation, digital transmission, space diversity techniques which reduce fading and spread-spectrum and frequency hopping methods.

[0014] In their paper entitled *Multiple Access Digital Microwave Radio System for Local Subscribers*, Nasatoshi Murakami et al. describe a radio communication system which provides point-to-multipoint digital transmission in a metropolitan area. See IEEE International Conference on Communications '83, June 1983, pp. b2.5.1.

[0015] In an article entitled *Digital Termination Systems*, Walter Urich and Ronald Bohm describe a common carrier service designed to provide flexible, low-cost digital communications within a community using a portion of the microwave spectrum. See Computerworld, 6 June 1984, pages 35-38.

[0016] In U.S. Patent No. 4,525,861 issued in 1985, Thomas Freeburg explains the details of his *Zoned Data Communications System for Communicating Message Signals between Portable Radios and a Host Computer*. This system serves a geographic area that is divided into a number of non-overlapping zones. Signals carrying alphanumeric information are conveyed among a general communications controller and a number of portable radios. See Freeburg, Abstract, Lines 1-9.

[0017] Douglas Morais describes a *Radio Communication System Using Frequency Division-Multiplexing for Transmission between a Master Station and a Plurality of Remote Stations* in his U.S. Patent No. 4,528,656, printed in 1985. Morais' point-to-multipoint radio communication system includes a master station and a number of remote stations which communicate using frequency division multiplexing.

[0018] Alfred Mack discusses his *Radio Communication System* in his U.S. Patent No. 4,633,463, granted in 1986. Mack's invention pertains to tactical military applications, and includes at least one remote station associated with each of several central stations. Each central station is connected to an omni-directional antenna, while each remote station is connected to a directional antenna. Each central station transmits at a distinct frequency, and each remote station is tuned to receive only the one frequency which is transmitted by its associated central station. See Mack, Abstract, Lines 1-11.

[0019] Minoru Kawano was granted U.S. Patent No. 4,704,733 for his *Cell Enhancer for Cellular Radio Telephone System Having Diversity Function* in 1987. His invention concerns a cell enhancer for use by one cellular provider in a cellular radio-telephone system. This cell enhancer has an "up-stream" antenna system directed at the cell site for receiving the transmitted down-link signal from the cell site. See Kawano, Abstract, Lines 1-10 and Column 2, Lines 38-42.

[0020] John R. Mihelich published a paper entitled *Mitchell Commits to Cellular Television Study* in the February, 1991 edition of Private Cable. Mihelich discusses the prospects for universal multi-channel cellular television service.

[0021] The greatest barrier to selectively delivering information to millions of diverse consumers resides at the network-customer interface or "last mile" in the communications network. Overcoming the enormous expense and complexity of supplying specific types of information to many different kinds of customers over this "last mile" has presented a major challenge to the telecommunications industry. The development of an intelligent and versatile local, multiple-point distribution system would constitute a major technological advance and would satisfy a long felt need in the telephone, entertainment and information businesses.

DISCLOSURE OF THE INVENTION

[0022] The present invention comprises a sectorized communication system that is intended as an extension of existing telecommunication networks or as a stand-alone system. The system is designed to support integrated broadband business links which can accommodate two-way videoconferencing, high-speed image and data distribution and multiplexed voice traffic. The present invention also provides residential services including video-on-demand, consumer-selectable television programming and interactive multimedia distribution. Residential telephone services supported by this novel system include voice service and low-speed data transmission.

[0023] One of the preferred embodiments of the invention functions as a one-way point-to-multipoint distribution network. A particular geographical region served by the system is mapped with cells that each include a number of wedge-shaped sectors. One or more transmitting antenna arrays are located at a node in each cell. Each transmitting antenna array includes one or more transmitting antennas. A transmitting antenna array is dedicated to serve only one of the sectors in the cell, and has a typical beamwidth of fifteen degrees or less. Receivers are located at customer

premises throughout the cells. Like the transmitting antenna array, each receiver is dedicated to operate only within the confines of a predetermined sector. Specifically, each receiver is limited to receive signals from only one of the transmitting antenna arrays. The signals conveyed by the first and second transmitting antenna arrays can be different or the same.

5 **[0024]** Another embodiment of the invention offers two-way cellular communications. Transmitting and receiving antenna arrays are installed at cell nodes assigned to each serve only one sector. Each transmitting and receiving antenna array includes at least one transmitting antenna and one receiving antenna. These transmitting and receiving antennas convey signals to and from transceivers residing at customer locations in the cell. Like the receivers in the preceding embodiment, the transceivers are constrained to communicate with a predetermined transmitting antenna and
10 a predetermined receiving array.

[0025] Connections between cells and between local service areas are made by means of interfaces to telecommunications network facilities, located at the cell nodes. Transmissions arriving over the external network may be fed to any sector or combination of sectors within a cell, leading to the possibility of reusing a block of licensed spectrum as many times as there are individual sectors installed.

15 **[0026]** The sectorized architecture incorporated into the present invention enables the embodiments described below to provide enhanced and versatile narrowcasting capabilities which are not generally offered by previous cellular communication systems. Novel beam shaping and polarization methods are employed to isolate beams serving adjacent cells.

20 **[0027]** The present invention can utilize dynamic channel allocation to maximize the utilization and re-use of the available frequency spectrum. Bandwidth may be allocated on demand by "intelligent" switching installed at the node of each cell. The system is also capable of disseminating program information to all subscribers and providing continuous monitoring of system faults.

25 **[0028]** An appreciation of other aims and objectives of the present invention and a more complete and comprehensive understanding of this invention may be achieved by studying the following description of a preferred and alternative embodiments and by referring to the accompanying drawings.

A BRIEF DESCRIPTION OF THE DRAWINGS

[0029]

30 Figures 1 and 2 are schematic illustrations of a sectorized communications system.

Figure 3 portrays sectors which are designed to selectively serve various geographical regions. The invention is capable of attenuating power output for sectors which are affected by adverse weather conditions.

35 Figure 4 illustrates a node which is able to provide different levels and bandwidths to sectors that have different communications requirements.

Figure 5 is a schematic depiction of the line of sight requirements for a sectorized antenna, which is shown communicating with business and residential subscribers.

40 Figures 6 and 7 are schematic diagrams of a planar antenna arrays which may be used in combination with one of the preferred embodiments of the present invention. The planar array shown in Figure 7 offers a more narrow bandwidth than the antenna shown in Figure 6.

Figures 8, 9, and 10 illustrate three potential channel usage diagrams for a sectorized cellular communication system. The available frequencies may be used for AM, FM, or digital television; broadband data; voice or select/control functions.

45 Figure 11 is a diagram that represents a system overview of one embodiment of the present invention. Individual sectorized cells receive signals from and transmit signals to a common, central network.

Figure 12 is a pictorial representation of the sectorized hub design utilized by one of the preferred embodiments of the present invention.

Figure 13 portrays the switching and transmission of signals as they arrive at the node transmitter.

50 Figure 14 depicts the distribution of various services that may be selected by individual consumers, including television programming and data and voice communication. Figure 15 depicts the same distribution of various services as shown in Figure 14, but in a dual-frequency system.

Figure 16 portrays a conventional cable TV network signal distribution system.

Figure 17 portrays a conventional telephone network system.

55 Figure 18 is an illustration of one of the preferred embodiments of the present invention as an extension of an existing telephone network.

Figures 19, 20, 21, 22, 23 and 24 are schematic illustrations of six different embodiments of the NarrowBeam™ System.

Figures 25 and 26 portray two-way communications between cellular nodes and televisions, computers and tele-

phones situated in residential and business environments.

Figure 27 exhibits an allocation of program channels that may be selected by a customer who subscribes to the advanced wireless cable service that may be offered using the present invention.

Figure 28 is an interdict table that may be utilized as a filter which blocks access to specific channels shown in Figure 27.

Figure 29 is a node block diagram.

Figure 30 depicts a switch which may be used in conjunction with embodiments of the present invention.

Figure 31 reveals the details of a point of presence (POP) interface.

Figure 32 is a diagram showing alternate point-to-point routing and links tailored to traffic density.

Figure 33 is a block diagram of a single user transceiver, while Figure 34 is a block diagram of a multi-user transceiver.

Figure 35 is a flow diagram that depicts both a wait state and a transmit condition.

Figure 36 shows antenna arrays transmitting signals to receivers situated in six sectors. The beams are alternately polarized to insure signal isolation between beams that serve adjacent sectors.

Figures 37, 38 and 39 are graphs that plot signal strength in dB versus signal strength received at three different sectors shown in Figure 36.

Figures 40 and 41 are graphs that compare the output of a conventional antenna with the beam-shaped output produced by the present invention.

Figures 42 and 43 reveal sectorized antenna arrays that serve three different receivers.

Figure 44 shows sectorized antenna arrays covered by a shroud.

Figures 45 and 46 are schematic block diagrams of circuits that may be used to implement active cancellation methods.

Figure 47 is a schematic illustration of block scrambling, while Figure 48 reveals a method for descrambling.

Figure 49 exhibits a technique for invalidating pirates.

Figure 50 relates to channel interdiction.

Figure 51 is a diagram that reveals a local switching function.

BEST MODE FOR CARRYING OUT THE INVENTION

[0030] Figure 1 is a schematic depiction of a preferred embodiment 10A of the present invention which offers one-way point-to-multipoint communications services. Figure 1 shows a cell 11 comprising two wedge-shaped sectors 12 & 14. Each sector 12, 14 is bounded by two radii and a length of arc along the circumference of the sectors. All sector radii extend from a point called a node, N. The first sector 12 is served by a first transmitting antenna array 15A located at the node N. Similarly, the second sector 14 is served by a second transmitting antenna array 17A. The first transmitting antenna array 15A includes one or more transmitting antennas 16, while the second transmitting antenna array 17A includes one or more transmitting antennas 18. Each cell 11 may vary in size from a single sector 12, 14 to an entire circular cell 11 served by a number of transmitting antenna arrays. Geographical regions that are served by the system are divided into a number of cells 11. The size of each sector 12, 14 and the cells 11 may be determined by a variety of factors, including the density of subscribers in a particular geographic region, and by the type of services these subscribers wish to receive.

[0031] For the sake of simplifying the description of a basic embodiment of the invention, Figure 1 shows only two transmitting antenna arrays, 15A and 17A. Each transmitting antenna array 15A, 17A is dedicated to serve only one of the sectors in the cell 11. In Figure 1, transmitting antenna array 15A serves only sector 12, while transmitting antenna array 17A serves only sector 14.

[0032] Each transmitting antenna array 15A, 17A is characterized by a beamwidth 19 that is not omni-directional. The beamwidth 19 of each of the transmitting antenna array 15A, 17A may be uniform or may be varied to suit particular applications, but is typically less than fifteen degrees of arc. Although some of the drawing figures show sectors which measure more than fifteen degrees of arc, this presentation is furnished only for the sake of clarity. In the preferred embodiment of the invention, the beamwidth 19 is less than fifteen degrees.

[0033] In the one-way embodiment 10A, fixed receivers 20 & 22 are located at customer premises throughout cell 11. As a simple example, Figure 1 depicts a receiver 20 in sector 12, and a receiver 22 in sector 14. All receivers are highly directional, and are limited to communicating with a single transmitting antenna array 15A or 17A that is assigned to exclusively serve a particular sector.

[0034] Figure 2 exhibits a two-way communications system 10B. As in Figure 1, cell 11 comprises sectors 12 & 14. The two-way system, however, utilizes transmitting and receiving antenna arrays 15B and 17B that each include at least one transmitting antenna and one receiving antenna instead of only transmitting antennas. Sector 12 is served by transmitting antenna 24T and receiving antenna 24R, while sector 14 is served by transmitting antenna 26T and receiving antenna 26R. In this embodiment, fixed transceivers 28 & 30 occupy sectors 12 & 14, respectively. Just as in the one-

way system 10A, each transceiving antenna array 15B, 17B has a limited beamwidth 19 that is not omni-directional, and each transmitting and receiving antenna array 15B, 17B is restricted to conveying signals only in one sector 12 or 14. The transceivers are similarly constrained to operate with particular transmitting and receiving arrays 28, 30. Signals originating at adjacent transmitting and receiving arrays as well as signals emanating from the transceivers in adjacent sectors may be characterized by different polarizations to reduce interference.

[0035] Figure 3 is a schematic depiction 34 which portrays sectors 12 & 14 that are designed to selectively serve various geographical regions. The sectorized communications system can be configured to serve only regions with desired customers 20 & 22. This configuration avoids the cost of providing signals to remote or sparsely populated areas RA, such as the offshore regions. By incorporating intelligence at the node N, various embodiments of the present invention are able to attenuate the signal power output for sectors 12 or 14 which are affected by adverse weather conditions, such as rain clouds RC.

[0036] Figure 4 is an illustration 36 which indicates how a node N is able to provide different levels and bandwidths to sectors that have different communications requirements. For a typical residential sector 38, the transmitting and receiving antenna arrays used at the node N might have a fairly wide band, providing typical signal transmission and reception of such services as television, telephone communication, and video on demand.

[0037] For regions requiring larger capacities of services such as data transmission, two-way audio or video, as indicated by the commercial community 40 in Figure 4, the transmitting and receiving antenna arrays chosen for the node N to serve the region might have a fairly narrow band.

[0038] Figure 5 is a schematic depiction 42 of the line of sight requirements for a sectorized antenna 46 as it communicates with subscribers in residential and business communities 38 and 40. The locations and configurations of particular sectorized antenna arrays are determined by the signal frequency and bandwidths needed for particular customers. Service to customers is required to be substantially line of sight between nodes N and customer interface units 44. Both natural and man-made structures, such as mountains M, trees TR, foliage and buildings B can diminish the effective area served by a sectorized antenna array. These obstacles may be overcome by careful placement of the arrays and by customizing antenna networks to adapt to specific local requirements.

[0039] In some neighborhoods, it may be desirable to locate the sectorized array 46 on a tall tower, building, mountain or similar object. Such a location enables the transmission of signals down to customers 38 and 40, and avoids many potential signal barriers. Sectorized antennas 46 can also be used to receive the broadcast signals and broadcast them below the level of obstacles such as foliage. These methods allow an increased percentage of area coverage for rural, hilly or urban areas.

[0040] The actual percentage of customers in a sector that can be served can vary by the geography and the local rainfall characteristics. A region like Miami or the Caribbean which experience heavy average rainfall may require smaller sectorized cells, to allow enhanced control of sector signal power. In dry, relatively flat areas, such as Phoenix, Arizona, the size of a cell 11 size might well be six to ten miles across, with antenna arrays located on local high points.

[0041] Figures 6 and 7 are schematic diagrams of a planar antenna arrays 47 and 50 which may be used in combination with embodiments of the present invention. Both the square and rectangular arrays 47 and 50 comprise a substrate 48 and feed terminals 49. The rectangular planar antenna array 50 shown in Figure 7 offers a more narrow bandwidth than the square planar antenna array 47 shown in Figure 6. These arrays may be used as the transmitting or receiving antenna arrays located at the nodes N of the system. Arrays located at the customer interface units 44 may also use similar devices for signal reception or transmission.

[0042] The square planar antenna array 48 shown in Figure 6 would provide a 2 degree by 2 degree beam. In most antenna arrays, it may be desirable to have greater horizontal coverage than 2 degrees together with tight control over the vertical disbursement of power. The coverage requirements for most sectors dictate that the planar antenna arrays should be rectangular, measuring approximately 12 inches high by 2 wide, as suggested by the more rectangular planar antenna array 50 shown in Figure 7.

[0043] The sectorized nature of the antenna array employed by the present invention affords the designer of the entire communication system a wide variety of options. Different types of planar antenna arrays 47 and 50 may be deployed at the node N to serve many different types of customers. Because the diverse antenna arrays are modular, the configuration of antenna arrays at any node may be easily changed at a minimal cost. If a narrow beamwidth is desirable, a large antenna array 47 or 50 may be utilized. A two degree array would be approximately 12 inches on a side. For sectors that would be used to serve residential customers, a 10 degree planar antenna array measuring approximately 3 inches across may be selected. Table One summarizes some of the available beamwidths and dimensions for planar antenna arrays that could be implemented in conjunction with the present invention.

Table One

Beamwidth in degrees	Dimension
0.5	36"
2	12"
5	72 sectors - 720 watts
10	3"
15	2"
90	1"

[0044] The range of potential sector sizes that could be served with this sectorized antenna array is only limited by the size of planar antenna arrays 47 and 50 that can be manufactured, and the ability to install them at a node N. A sector covering only one half of one degree would utilize an antenna array that would be about three feet on a side.

[0045] For most applications, the smallest planar antenna array might be approximately 5 degrees, and the largest might be 15 degrees. For an array serving customers in all directions with 10 watt, 5 degree planar array antennas, the total power output from the 72 sectors at the broadcast node would be 720 watts, significantly higher than the broadcast power from conventional broadcast antennas.

[0046] The significance of the this increased power allowed by the present invention is related to the fact that number of homes that reside in a particular sector increases with the square of the radius measured out from the node. If the antenna array has increased available power to transmit and receive signals, the market potential for the system is greatly enhanced.

[0047] Figures 8, 9, and 10 illustrate three potential channel usage diagrams 52, 54 & 56 for a sectorized cellular communication system. The available frequencies may be used for amplitude modulation (AM), frequency modulation (FM), or digital television; broadband data; voice or select/control functions. The signal frequencies shown in the drawings are used throughout the other figures to show the transmission and reception of signals through the antenna arrays, and also enhance the description of the services offered by various embodiments.

[0048] For each of the 1,000 MHz blocks 52, 54 & 56 shown in Figures 8, 9, and 10, the potential channel assignments can be allocated in any combination that would provide the greatest benefit to the customers in a region. Figure 8 shows an allocation of bandwidth blocks 52 that might be in demand at the present time for many locations, with AM TV channels, digital TV signals, and channels for selection and control. Figures 9 and 10 show other potential channel assignments 54 and 56 for the bandwidth blocks. As the available services change, the present invention is able to vary the available allocation to different types of channels.

[0049] Figure 11 is a diagram that depicts a system overview 58 of the present invention. Individual sectorized cells 11 receive signals from and transmit signals to a common, central network through the sectorized antennas 46.

[0050] As the system 58 grows, its capacity can be increased by using a frequency hopping technique of taking a whole bandwidth block 52, 54 or 56 and moving it up and down, on a substantially random basis. For example, for two sectors 12 and 14 served by the same antenna array, each sector is served by its own set of planar array antennas. Each installed antenna may would be assigned a licensed bandwidth block of 1,000 MHz, either from 27.5 to 28.5 GHz or from 28 to 29.5 GHz. As an alternative, the 38 GHz band may also be utilized. When first installed, all customer interface units 44 within the sectors served by the antenna array might receive the same signal feed signals. As traffic builds, sectors 12 or 14 could be separated to receive different feeds to increase the available capacity to each sector 12 or 14. This modular approach allows the maximum service capacity equal to the product of the number of sectors 12 or 14 times the number of cells 11.

[0051] Figure 12 is a pictorial representation of the sectorized hub design 62 utilized by one of the embodiments of the present invention. The antenna configuration is shown as it might be mounted on a tower or a pole P. The pole supports a number of transmitting and receiving antenna arrays 50, which are typically paired up to serve individual sectors 12 or 14. Although the configuration shown in Figure 12 incorporates service for six sectors, a typical design may include service to twenty four to over seventy two sectors. The individual transmitting antenna arrays 50 generate a sector's worth of outgoing signals 64, and the individual receiving arrays 50 receive all incoming signals 66 from a specific sector. All received signals are fed into the telephone network 60, or into a dedicated network 68. All signals destined to be transmitted from the transmitting antenna arrays originates from the telephone network 60, or from the dedicated network 68.

[0052] Connections to the telephone network 60 or dedicated network servers 68 can be achieved by two methods.

One preferred method involves connecting the antenna arrays to the telephone network through a fiber link FL, thus avoiding signal interference from other signals or weather. An advantage of using fiber links FL is that they allow for enhanced system capacity. As more subscribers and services are provided through the system, such as audio, video, and data services, additional fiber links FL can be installed to support the increased demand.

[0053] Point-to-point microwave links 70 may also be used to connect together different hubs. These links 70 employ narrow beam antennas 72. In this embodiment, one half degree transmitting and receiving antenna arrays might be employed. Point-to-point microwave links 70 can transmit or receive 1,000 MHz signals directly from the telephone network 60. This arrangement may provide a means to add new antenna arrays to the system 58 for particular regions, such as those where fiber links have not been installed.

[0054] Figure 13 presents a diagram 71 which portrays the switching, up-conversion and transmission of signals from a TV head-end 73, signals from a video server 74 and signals from a public switched telephone network 75. These signals 73, 74 and 75 arrive at switch circuitry 76, and depart the switch circuitry 76 as fixed blocks 77, switched channels 78 and fixed channels 79. These outputs 77, 78 and 79 flow through up-converters 80 to node transmitter 82.

[0055] Figure 14 is a diagram 81 which depicts the distribution of various services 78 through the node receiver 82 that may be selected by individual consumers. Services may be requested over switched channels 78 using a television TV, over dedicated channels 86 using a personal computer PC or may be initiated by an off-hook signal 84 using a telephone TP. A one-way transmission 88 emanated from the node receiver 82 is fed to a demultiplexer 89 which, in turn, conveys the requests to the telephone network 60. Various options may include television programming and data and voice communication. Within a particular sector, several different kinds of service connections can be provided, including service to wired or cordless telephones TP, to data devices such as personal computers PC with modems, to interactive interface units IIU, or to televisions TV. The network 58 will be able to provide service to digital telephone services as well, such as digital cellular systems.

[0056] The service connection to analog telephones TP would usually be a permanent allocation, with dedicated channels 86 being allocated through by a controller 32. This dedicated channel allocation would allow the customer to have instant communication access, without waiting for polling to take place in the system. Individual analog voice channels require only about 4 KHz of bandwidth, so the burden of dedicated phone line access 86 on the total system frequency spectrum is minimal. Most telephone networks carry analog signals until they reach the electronic switching systems ESS, where the analog signals are converted to digital signals for further distribution.

[0057] The dedicated channel access 86 would provide convenient operation for its users. The customer would pick up the receiver of the telephone TP, which would generate an off-hook signal 84 through the channel 86 to the switch ESS (not shown) at the public switched telephone network. The outgoing channel is already assigned to the customer's phone TP, which allows the signal to go through the ESS to a second phone TP. The system 58 also provides the return channel 86 to the customer's phone TP from the second phone TP. A full duplex transmission is provided both directions, using a pair of channels 86. Every telephone instrument TP in the system would have two narrowband channels associated with it, and one controller 32 that it connects through to the public switched telephone network 60 (PSTN).

[0058] System connections to personal computers PC with modems could be supplied with permanent channel allocations 86 in a similar method to channel allocations 86 for telephone service. Broader channels could be provided for the faster speed requirements of data communication through computer modems.

[0059] For connections that require larger bandwidths, such as the transmission of video signals, the switching of channels would be used, using a polling process. The electronics within the node controller 32 would scan the incoming signals for any video channel service requests from customers. The controller 32 would respond to an incoming video request by allocating a channel 78 to the requesting customer's interface unit 44 for the transmission of the video signal.

[0060] These switched video channels 78 would be used for a variety of services, such as video-on-demand or interactive video services. The controller 32 is capable of identifying that a request is being made. The controller 32 would also examine the request to approve or disapprove the service.

[0061] Interactive requests would also be possible with this type of service. The node controller 32 could supply information on available upcoming programming, either directly, by publishing transmission schedules, or by customer prompting, such as if asked by a customer for a list of upcoming western movies. This intelligent information access at the controller 32 would be downloaded from each server 68 that provides broadcast services, which might include information on upcoming free, premium, pay-per-view, or special event programs. The controller 32 would keep a table of programming provided by every server 68, and would sort each database into a node table that could be used by the customers through a menu selection process.

Dual-Frequency System

[0062] As an alternative implementation to accomplish specific objectives of wireless distribution, the system shown in Figure 15 could be used. Figure 15 presents a diagram 83 which depicts the distribution of various services 78 through the node transmitter 87 to individual consumers. Telephones TP are connected to the transmitter 87 through

up/down converters 85. A two-way transmission 90 flows between the node transmitter 87 and demultiplexer 89 which, in turn, is coupled to the telephone network 60. In the dual-frequency embodiment, a second, lower frequency such as 900 MHz is used in conjunction with the microwave bandwidth used for video and other broadband transmissions. Up- and down- conversion units would be placed at the nodes to convert signals between the two frequency ranges. A low-frequency base station at the customer premises might also form part of the design. Control and switching functions similar to those performed for an all-microwave system would also be available for transmissions making use of the second frequency band.

[0063] The principal purpose served by the lower-frequency portion of this system would be to provide freedom from line-of-sight restrictions for services such as cordless telephones. Low-power television distribution might also be envisioned.

[0064] Figure 16 is a diagram 91 which portrays a conventional cable TV network signal distribution system that includes switches 92 and customer terminals 93. Figure 17 is a diagram 94 that portrays a conventional telephone network 60 connected to switches 92 and customer terminals 93.

[0065] Figure 18 is an illustration 95 of one of the embodiments of the present invention that can function as an extension of an existing data network. A typical application for this embodiment could be video distribution. Servers 96 that are attached to the network 60 would supply information, such as film libraries or games. The telephone network 60 used for such an embodiment would require broadband switching and sufficient trunking capacity. Servers 96 supplying these services would be connected throughout the network 60.

[0066] One option for this system embodiment would be to install dedicated fiber links 98 between the servers 96 and the antenna arrays to supply signals directly. Another option shown would be to install dedicated links 99 between antenna arrays, which would allow passing information from one array to another. In this embodiment, dedicated fiber links 99 are employed, although they could be point-to-point microwave links 70. One array shown in Figure 18 has a direct fiber trunk 98 to the network 60, and another uses a dedicated fiber link 99 for the purpose of distributing information from servers 96 to an array in the system.

[0067] In the one embodiment of the invention, the telephone company network would use broadband capacity electronic switching system 97, which can each handle thousands of lines. In another embodiment, where broadband capacity switching is not offered by the local telephone company network 60, the switching function operations can be provided directly at the antenna arrays. The arrays would receive a single incoming channel, and either:

- a) route it to the customer(s) programmed to receive it within the territory, or
- b) generate a point to multi-point distribution.

[0068] The present invention includes six alternative embodiments shown in Figures 19, 20, 21, 22, 23 and 24, which are each described below in increasing order of their functionality. Table Two identifies the key characteristics of these six alternative embodiments.

Table Two

System/Figure	Node Intelligence	CIU Intelligence	Outbound Channels	Return Channels	Functions Added over Previous Embodiment
1/19	No	No	Fixed	None	Transparent One-way Information Distribution
2/20	Yes	No	Fixed	None	Monitoring and Reporting Node Performance
3/21	Yes	Yes	Fixed	Shared	Implementing Requests. Dynamic Power Control. Monitoring CPU Performance.
4/22	Yes	Yes	Fixed	Fixed	Full-Duplex Services

Table Two (continued)

System/Figure	Node Intelligence	CIU Intelligence	Outbound Channels	Return Channels	Functions Added over Previous Embodiment
5/23	Yes	Yes	Switched	Fixed	Shared Outbound Channels
6/24	Yes	Yes	Switched	Switched	Shared Return Channels

[0069] For the six embodiments described below, the system 58 is used as a telephone network extension. In these embodiments, central serving, switching and control capabilities are externally located. Alternative embodiments may incorporate these functions within the system, which can provide additional features or services.

Level 1 System

[0070] Figure 19 depicts the most basic Level 1 embodiment 101 of the present invention. The antenna array is used as part of a one-way distribution system for wireless cable or any similar service. Incoming analog or digital signals are received from the network 60, passed through interface modules 103, up-converters 104 and multiplexers 105 en route to a transmit may 106. The signals are up-converted into the 28 GHz range and multiplexed on a frequency division (FDM) basis into a single block corresponding to the band licensed for Local Multi-Point Distribution System (LMDS) transmission.

[0071] At the receiving site, the customer interface unit 44 is a receive-only device that down-converts the entire LMDS block 102 into a baseband or IF frequency range and outputs the block on a cable for subsequent tuning by a set-top box or other device. A pilot signal contained within the licensed block 102 is transmitted continuously from the antenna arrays to all customer interface units 44 through CIU receiving antenna arrays 107, for their use in performing the down-conversion function.

[0072] As an option, instead of passing a full LDMS block on to a connected device, the CIU 44 can include a fixed filter that will isolate a single channel. The location and bandwidth of the passed channel will be determined by the filter module installed. With this design, a device not having a built-in tuner can be connected directly to the system for receiving information.

[0073] The Level 1 System 101 has no intelligence anywhere within the system. Any intelligent functions required by the application must be assigned either to a customer interface device or to a unit in the telephone company network 60.

[0074] A typical application for this Level 1 System 101 would be for the distribution of wireless cable television programming. The system would act as a transparent link in the "last mile" of the programming distribution. The system network that would feed into the controllers 32 might look like that in Figure 11 or 18, in which a series of sectorized cells 11, each made up of multiple sectors, would be used to distribute the signals. In one of the embodiments, each of the cells 11 are made up of at least twenty four sectors.

[0075] The node controller 32, located at the origin point of each sectorized cell 11, would receive a block of television programming material from the system network, on a coaxial or fiber-optic cable or other suitable signal transmission means. The controller 32 upconverts the signal to the 20-28 GHz radio frequency band, and broadcasts the upconverted signal to each of its sectors. In this Level One System 101, no control or power output would be handled at the controller 32. The signal which is processed and broadcast by the controllers 32 is multiplexed and may be characterized by a variety of forms. An interface box might be used to provide multiplexing functions in systems where the incoming signal is not in a form that can be received by the CIUs 44. This might be an analog or digital frequency multiplexed signal (FDM).

[0076] The converted signal, transmitted from the antenna arrays, is received by the customer interface units 44 located in each of the sectors and served by the antenna arrays. The CIUs 44 receive the whole block of broadcast FDM signals, and down-convert these FDM signals into a suitable range for the televisions TV connected to them. This type of system does not require a set-top box STB. The television tuner would be used by the customer to select the desired channel from all the available channels.

Level 2 System

[0077] The second functional level 108, as shown in Figure 20, includes a general-purpose processor that acts as a controller 32 for the sectorized antenna array 46, and another processor at the CIU 44. A variety of functions can be

performed by this configuration. One such function would be that of monitoring the operation of the sectorized antenna arrays present in its cell 11. With equipment in place to measure output power levels for each sector, the controller 32 can sample these readings periodically and apply program logic to detect the deteriorating trends in any system element. When a potential problem is identified, the node controller 32 can transmit a warning to the telephone company's central office for maintenance attention. By this means, it should be possible to eliminate most calls for emergency repairs on the antenna arrays, and ensure maximum continuity of the service.

[0078] A second function for the node controller 32 in the Level 2 System 108 would be that of providing security for the signals transmitted from the node, by performing block scrambling using frequency-hopping techniques. The CIU controller 114 would unscramble the transmission by making use of a secret code stored in its memory, as described elsewhere.

[0079] Still another level of functionality would involve the joint operation of the node and CIU controllers to perform positive interdiction services, inhibiting the ability of the customer to access unauthorized programming on a channel-by-channel basis.

Level 3 System

[0080] Figure 21 provides a schematic view of the Level 3 System 110. At this level, a shared return channel 112 is generated which is used to relay requests for service from the CIU 44 to the controller 32. This design supports applications such as video on demand. With the narrowband return channel used to select programming, request information, and place orders for pay-per-view services.

[0081] Performance of these functions requires of intelligence at both the controller 32 and at the CIU 44. The CIU controller 114 accepts service requests from an attached device and buffers the request codes and associated information in memory until a polling signal is received from the controller 32, transmitted over the pilot channel or another channel reserved for the purpose. When its polling address is received, the CIU controller 114 transmits this stored information over the shared channel back to the node. Relatively little data must be sent to specify a request. Accordingly, the data rate on the shared channel can be low-- typically from 16 KBPS to as much as 1 MBPS, if many CIUs 44 are expected to participate.

[0082] Sharing of the return channel 112 can be accomplished in several ways. The simplest design is the polling approach described above. Other alternatives are:

Time division multiplexing, with each CIU 44 assigned a slot in the time domain during which it can transmit all or part of its message; or

Contention, using a technique such as those employed in the Aloha or Ethernet networks, whereby a CIU 44 can determine the availability of the shared return channel 112 and seize control.

[0083] The spectrum efficiency of the shared channel 112 may be designed to be very low, in order to achieve a low cost implementation. As only one channel is involved, assigning extra bandwidth does not significantly affect system capacity.

[0084] Upon receipt of a service request, the controller 32 can perform a number of useful functions. These might include:

Determining the validity of a request by examining a code transmitted from the CIU 44;

Providing program information and navigation assistance, using a data base downloaded periodically from the server centers 96;

Advertising coming attractions and commercial products, and accepting orders to upgrade service or to receive specific offerings such as pay-per-view programs;

Collecting billing data for transmission on demand to the billing office; and

Reporting failures in individual wireless loops or CIUs 44.

[0085] By monitoring the strength of the signal received from each CIU 44, the node controller 32 can undertake to control its output power in a sector-by-sector basis, in order to improve system performance during conditions of heavy rainfall. When a storm front moves through a particular sector, the controllers 32 can use dynamic power controls to boost the signal power to the affected sector; and then return the signal power to a lower level as the storm passes. If necessary, instrumentation to measure the signal strength from the antenna arrays can be built into some or all CIUs 44, and the current reading would be included in the polling response.

[0086] This sector-by-sector dynamic signal control has distinct advantages over previous omni-directional systems. By limiting the boost in signal power to only sectors influenced by rainfall, the risk of burning out CIUs 44 in unaf-

affected sectors is minimized. In prior omni-directional systems, the amount that the signal power could be increased to all customers was limited to the maximum power limit of all customers. The present invention, which utilizes many narrow sectors, allows signal power to be boosted in only the affected sectors, leaving the other sectors untouched. Since rainstorms can vary widely in size, this system ability provides distinct advantages over previous systems.

[0087] The intelligence in the CIU 44 can also be employed to perform additional functions to assist customers in using the system. For example, menus for program selection could be stored in memory, along with a set of help messages to assist in explaining their use. By implementing this capability, in conjunction with the increased functionality of the controller 32, many of the routine navigation functions needed for advanced video services could be accomplished without the need for an expensive set-top box STB.

[0088] Various approaches to CIU antenna design may be used for the Level 3 system 110. It may be possible to use the receive antenna for the return path, either by using a circulator or by time-sharing techniques. A small CIU transmitting antenna 117 could also be used, which would be separated by a few inches from the CIU receiving antenna 116.

Level 4 System

[0089] Figure 22 depicts a fourth level of the system 118 that is designed to permit two-way broadband communication. A CIU transmit antenna 117, approximately equal in size to the CIU receive antenna 116, has been incorporated in the CIU 44. The transmitter 106 feeding this antenna 117 will operate on a fixed-channel, established at the time this unit is installed. With circuitry at the antenna arrays to identify and trap requests on the return channels, the controller 32 would be capable of performing similar control functions to those of the Level 3 system 110.

[0090] As an option to the design shown in Figure 4, a processor/controller 114 similar to that shown in Figure 21 would be added to the Level 4 CIU 44. With this addition, plus request code traps, the Level 4 System 118 would have full control functionality. A shared channel would be used for communications from the antenna arrays; while the controller 32 would identify requested actions by scanning a table corresponding to the CIU polling sequence.

Level 5 System

[0091] Figure 23 portrays a level five system 120, with intelligent controllers 32 and 114 installed at both the antenna arrays 46 and the CIU 44. This configuration makes it possible to perform a cross-connect switching function on the transmissions entering the system from the telephone company network 60. The purpose of providing this function would be to reduce the demands on the network facilities outside LMDS-- the servers, switches, and distribution plant required to deliver information to the antenna arrays.

[0092] To implement the Level 5 design 120, the CIU 44 must incorporate a frequency controller which, operating under the command of the CIU controller 114, is capable of tuning the output from the unit to any channel available in the LMDS block. When a service request is made through the CIU 44, the controller 32 logs the incoming call and reserves a channel for the requested transmission. It then forwards the request to the appropriate server center 96, which acknowledges the request and indicates which of the channels connecting it to the antenna arrays will be used for the transmission. Over the shared control channel, the controller 32 issues instructions to the CIU 44 to tune to the local channel that it has reserved. At the antenna arrays, it resets the up-converter 104 assigned to the transmission from the server center 96, in order that the incoming signal will be transmitted on the proper LMDS channel 102. In the same way, a single incoming transmission can become a point-to-multipoint distribution, simply by instructing multiple CIUs 44 to tune to the same channel.

[0093] As an alternative to this approach, a standard cross-connect switch might be installed at the antenna arrays. Operating under the command of the controller 32, this unit would be capable of connecting any incoming transmission with any LMDS channel. Under this arrangement, the up-converters 104 at the antenna arrays, as well as the CIU receivers 116, could continue to operate at fixed bandpass frequencies. Additional flexibility and functions such as bandwidth on demand requires a tunable CIU receiver 116.

Level 6 System

[0094] At the sixth level system 122, the same switching function performed for incoming transmissions in the Level 5 system 120 are extended to transmissions originating at the CIU 44. This design provides increased flexibility for handling full-duplex communications such as voice service. Level 6 also allows operation with fewer channels than customers, in recognition of the fact that circuit occupancy for this type of device is always well below 100%.

[0095] The switching of outbound channels can be accomplished simply by using a frequency synthesizer in the CIU 44 that is capable of being tuned under command of the node controller 32. To create a full duplex circuit, a pair of channels would be assigned to the CIU 44 at either end. The transmitter of each would be tuned to the frequency

assigned to the other's receiver.

[0096] As with the Level 5 design 120, a similar function might be performed through the use of a cross-connect switch at the antenna arrays. In this case, transmissions from the CIU 44 would always be made in the same frequency band, but the switch would be set by the controller 32 to route the signal to the appropriate port for entry into the telephone company network.

[0097] Figures 25 and 26 present diagrams which portray two-way communications between cellular nodes and televisions TV, personal computers PC and telephones TP situated in single family residential 124 and multiple dwelling 126 environments. A residential antenna 125 is shown on the buildings in both Figures 25 and 26.

[0098] Figure 27 exhibits an allocation 128 of program channels that may be selected by a customer who subscribes to the advanced wireless cable service that may be offered using the present invention. The first allocated channels are standard broadcast channels 130 available to every subscriber, which in this example consists of fifteen channels. For an additional fee, the subscriber could receive one or more blocks of additional broadcast channels 132, 134 & 136 from one or more providers through the broadcast node, which in this example are blocks 132 and 134, which in this example are each carrying 30 channels. Blocks 132 and 134 may also provide optional premium channels 136, such as movie, sports, news, or special interest channels, which would be available to the subscribers for an extra fee.

[0099] To order additional services, the subscriber could either call the service directly, or, for system embodiments that include control channels back to the network 60, the subscriber could order the desired services directly through a set-top box STB or some other interface unit.

[0100] One embodiment of the present invention uses a pair of notch filters to provide customer access to blocks 132 and 134. The notch filters, installed at the customer's interface box, would allow three alternatives; block 132 service, block 134 service, or both block 132 and 134 service.

[0101] The first thirty channels provided by block 132 may be provided by a primary common carrier, while the second thirty channels provided by block 134 might be provided by secondary supplier who requests available access to the local broadcast spectrum. The total bandwidth required for blocks 132 and 134 may be on the order of 1 GHz.

[0102] For non-subscription pay-per-view services and interactive programming and communication, a set-top box STB would usually be required at the customer location, such as manufactured by Hewlett-Packard™ or Scientific Atlanta™. For instances where interdiction is available, pay-per-view services may be available without a set-top box STB. Where used, the set-top box STB would send the outgoing signals to the antenna arrays through the CIU 44.

[0103] Figure 28 is an interdict table 138 that may be utilized as a filter which blocks access to specific channels shown in Figure 15. Implementation of the interdict table may be achieved through the use of filters or synthesizers. If filters are used on every channel, the filters would be set either on or off at the antenna arrays or from a central location, depending on the customer order. Upon a request for a change in service, a new interdict table 138 would be implemented for the customer to add or remove available channels, by using appropriate logical values of "0" or "1" within the interdict table 138.

[0104] The use of synthesizers to implement the interdict table 138 would require the synthesizers to block or enable transmission of selected channel signals, with each channel covering approximately 6 MHz of bandwidth. For residential users, the interdict table 138 may operate at the CIU 44 to control access to channels for the entire household. For service to apartment buildings 126, it may be desirable to use a single front-end CIU 44, while using separate interdict tables 138 to provide different services to different customers at the site. A single control box could be used to control access to the customer television set or other connected devices.

[0105] With an outgoing channel to provide channel requests back to the network 60 by the viewer, interdiction could take place between the controller 32 and the set-top box STB on each television set TV to provide or to restrict access to channels. Blocking channels could be achieved either by simply blocking or scrambling the signal, or by replacing the signal with a prompt that could explain, on the viewer's television screen, how to request the service.

[0106] Figure 29 is a node block diagram which reveals the flow of signals from the transmitting and receiving antennas through controller 32 to fiber trunks 142. Fiber trunks 142 carry signals into optical/electrical converter 144, a demultiplexer 89, independent up- and down- converters 148, a frequency domain modulation multiplexer/up converter 150 and a transmitter 152. Signal and control links 146 connect the demultiplexer 89 to a controller 151. The lower half of the node block diagram 140 contains a receiver 154 which feeds signals to a frequency domain modulation multiplexer/down converter 156, converters 148, a multiplexer 105, an electrical/optical converter 157 and finally out to fiber trunks 142. Signal and control links 146 connect the multiplexer 105 to controller 151.

[0107] Figure 30 exhibits a block diagram 158 for a generalized switch. Demultiplexers for a first, a second and a third sector 160, 164 and 168 are coupled via single channel buses 161 to sets of switches 163 to multiplexers 162, 166 and 170 dedicated to each of the three sectors. The switch 158 shown in Figure 30 may be used in conjunction with various embodiments of the present invention. In a small network which only supports local subscribers, service may be provided by supplying the composite received signal to the antenna arrays and by controlling traffic through end-to-end channel assignments. Larger networks call for frequency reuse to manage higher traffic volume. Some form of

switching must be employed if local calls are allowed to cross sector boundaries. In addition, many calls conveyed by the system are likely to be long distance calls. Since a 1 GHz bandwidth is insufficient to serve the call traffic for the entire United States, each region that is served must be free to make its own local channel assignments independently.

[0108] One embodiment of the present invention overcomes the enormous challenge posed by this switching requirement using the switch shown in Figure 30. One requirement of this design is that the same channel be assigned in all sectors designated to receive a particular transmission. For example, Channel 1 in Sector 1 may communicate with Channel 1 in Sectors 2 and 3, but not to any other channel. By imposing this constraint, the need to up- and down-convert frequencies between channels is avoided.

[0109] Multiple access from Channel 1, Sector 1 to two or more other Channel 1's in other sectors necessitates the use of a series of buses. One bus for each channel conducts the demux outputs into the appropriate slots in the muxes for all sectors, including Sector 1. Switching is performed after the bus, by opening the connections to any sectors that are not intended to receive the transmission. This innovative design greatly reduces the number of connections needed, and concomitantly affords dramatic cost savings.

[0110] Figure 31 reveals the details of a POP interface 172, which is used as an interface for sending and receiving long distance calls. Demultiplexers for a first and a second sector 160, 164 are coupled via single channel buses 161 to sets of switches 163 to multiplexers 162 and 166 which are dedicated to the first and second sectors. A POP demultiplexer 174 is connected through variable up-converters 176 through a set of switches 178 and variable down-converters 180 to a POP multiplexer 182.

[0111] Each demultiplexer 160, 164, 174 or single line is routed through a variable up-converter switch 176, which, under computer control, adjusts the incoming baseband or IF signal to that of the local channel assigned. Exiting the converter, each data channel is connected through switches 163 to all buses carrying channels of its bandwidth. In Figure 31, Signal A is connected only to the Channel 1 bus. Signals B and C have the same bandwidth, and are connected to both the Channel 2 and Channel 3 buses. Sector-to-sector switching requires that the signal be placed on the specific channels which are designated to receive it by disabling the switches on all other channels.

[0112] In the case of outgoing long distance calls, a similar approach is employed. Traffic from any channel is directed by switches toward channels of appropriate bandwidth on the POP multiplexer 182. Variable down-converters 180 will adjust the frequencies of these signals to baseband or any other levels required by the specific interface involved.

[0113] As the system expands, additional point-to-point links can be installed to carry information from the added sectors to all cells. Figure 32 presents diagrams showing alternate point-to-point routing 184 and links tailored to traffic density 188. The diagrams reveal signal pathways conveyed among sectorized antennas 46. The location of the city center is represented by reference character 186.

[0114] Figures 33 and 34 portray the single and multiple user transceivers that may be employed to implement the present invention. Figure 33 is a block diagram of a single user transceiver 196 mounted on the rooftop 192 of an office building 194. The transceiver 196 includes an antenna 198, a local oscillator 200, a modem 202, a fiber interface 204, control circuitry 206, and is connected to a DC power supply 208 and a fiber interface 212 inside the building 194. The interface 212 in the building is coupled to a coder/decoder 214 and to the particular device 214 used by the customer.

[0115] Figure 34 is a block diagram of a multi-user transceiver 216 mounted on the roof 192 of a building 194 that utilizes two antennas 198 and 199. The transceiver 216 comprises a multiplexer 105, a local oscillator 200, demodulators 218-220, control circuitry 22, modulators 224-226, and fiber optic interfaces 228. The transceiver 216 is connected to a DC power supply 208 and to fiber optic interfaces 230 inside the building 194. Within the building, the interfaces 230 are linked to half-duplex (HD) and full-duplex (FD) devices 232 and 234.

[0116] The antennas 198, 199 used for the transceiver would be about eight to nine inches long, and have a gain of about 31 to 32 dB. These transceivers 196, 216 are capable of handling a full 1 GHz of spectrum without division into smaller blocks. They have the ability to select a channel of any bandwidth from anywhere in the full range under local control, as well as possessing send and receive capabilities at the device interface level in half-duplex mode. The transceivers 196, 216 exhibited in Figures 33 and 34 would support fiber optic connections carrying baseband information between a remote RF unit and an interface unit located at the connected device.

[0117] The multiple-user design would nominally support ten channels, and would require a pair of antennas 198, 199. The incoming signal would be routed to parallel demodulators 218-220, each dynamically tuned to a different channel. Their baseband outputs would be fed along fiber optic cables to the individual device interface units. An alternative embodiment also calls for multidrop connections that may be made to these cables for providing "party line" service on a contention basis. The return channels parallel the incoming channels, but in this case, the signals emerging from parallel modulators must be combined in an FDM multiplexer before transmission.

[0118] Figure 35 is a flow diagram that depicts both a wait state 236 and a transmit condition 248. The upper half of the diagram reveals an antenna 198 coupled through a control channel 238 to a modem 202, a switch 240 and a device 246. The modem 202 is also linked to control circuitry 242, while the switch is also linked to a buffer 244. The lower half of the diagram shows the same components feeding signals to the antenna 198 through a data channel 250.

Polarization Control for isolation of Adjacent Sectors

[0119] One of the important features of the present invention is that the transmitting antenna rays are capable of forming a highly controllable and well defined pencil beam pattern. While it is not possible to roll the antenna sidelobe off very far (on the order of 20 dB or so) within the first portion of the first beam width, the present invention is capable of rolling off sidelobe within the next beam width. In one embodiment of the invention, each sector of the cell is illuminated with a modified pencil beam antenna pattern. The resulting transmitting pattern illuminates a wedge shaped sector radiating out from the node. The antenna pattern is formed so that the adjacent sector is begun at approximately the 3 dB roll off of the central antenna pattern. The signals from one sector are kept from the signals in the adjacent sector by using orthogonal polarization techniques. Polarization is used in the adjacent sector because it is physically impossible to have a practical roll off of on the order of 20 dB in the few inches or few feet of distance separating one sector from another. (This turns out to be a few hundredths of a degree in the antenna pattern.) It is possible to produce antenna roll off on the order of 20 dB one beam pattern away.

[0120] In the third sector over from the main beam, the antenna pattern has rolled off enough (on the order of 20 dB or more) to have enough isolation that a reasonably error corrected signal will work very well. It should be noted that this third sector three utilizes the same polarization as the first sector. As a consequence, no isolation is maintained between odd or even numbered sectors based on alternate polarization alone.

[0121] The polarization isolation provides 20 to 30 dB of isolation even if the antenna rays that serve different sectors are in the same physical space (separated only by the size of the respective antennas). Better performance can be realized by implementing low side lobe or shaped beam antennas. An antenna array with a uniform illumination will produce a sidelobe that is 13 dB lower than the main antenna's gain at the center of the beam. This first sidelobe can be reduced to 20 or 30 dB with proper attention to design of the amplitude and phase characteristics of each radiating element. These antennas are used to ensure that the next sector over receives interfering signals from the once removed adjacent sector that are 7 to 17 dB lower in size. The signal to noise ratio is also enhanced using this technique.

[0122] Figure 36 depicts a sectorized antenna 46 that includes a hexagonal array 258. Six transmitting antenna arrays 261, 262, 263, 264, 265 and 266 serve six sectors 271, 272, 273, 274, 275 and 276 numbered counter-clockwise from 1 to 6. Three receivers 294, 295 and 296 are shown in sectors numbered 4, 5 and 6. The signal 284 transmitted by the antenna array 4 will be received at full strength by receiver 4 because the antenna polarization is the same as the sector transmitter 264. The receiver 295 in sector 5 will reject the signal 294 transmitted by antenna array 4, because arrays 4 and 5 are alternately polarized with vertical and horizontal signals. Each antenna array on the pole P is alternately polarized, so that signals transmitted to adjacent sectors will not interfere.

[0123] All the even numbered arrays (2, 4 and 6) are polarized differently from all the odd numbered arrays (1, 3 and 5). As a consequence, the alternate polarization scheme will not reduce interference among the even numbered sectors or among the odd numbered sectors.

[0124] The isolation between even and odd numbered sectors is accomplished via the novel antenna pattern roll off technique illustrated in Figures 37, 38 and 39. These three figures supply graphs that plot signal strength in dB versus signal strength received at three different sectors. Figures 37, 38 and 39 illustrate how interference among even or odd numbered sectors is substantially reduced through the implementation of the novel antenna roll off method. Each beam is shaped so that most of the energy from a given antenna array is directed only toward the sector it serves. Even though receivers in sectors 1, 3 and 5 or the receivers in sectors 2, 4 or 6 sense the same type of polarized signal, the different signals destined for each one of those similarly-polarized sectors is isolated. The implementation of this antenna roll-off method does require an even number of antenna arrays at any given node. At the 28 GHz frequency band, one may utilize from about 6 to 200 sectors per node. This same method of using sectorized antenna arrays combined with alternate polarization to isolate adjacent sectors works equally well in the reverse mode for transmitting information from users in the area of the node to the node itself. In this case, the pencil beam antennas at the node are designed to receive signals, and they reject signals from the adjacent sector by using the same concept of reverse polarity. It may also be beneficial to use one set of polarities during transmission and the opposite set of polarities during reception to reuse the same frequencies twice.

Use of Shaped Beam or Ultra Low Sidelobe Antennas to Improve Signal to Noise in Adjacent Sectors

[0125] An additional aspect which may be implemented in conjunction with the system described above is to use low sidelobe antennas as the transmitter sources at the node. This gives the advantage of reducing the sidelobe in the one over adjacent sectors where the polarization is again the same as for the transmitting antenna. There are two basic approaches. The first involves using antennas which distribute power to the individual radiating elements so that the center-most elements radiate more power than the elements at the periphery of the antenna. In this fashion, the first sidelobe exposed to the one over adjacent sector is substantially lower. This results in a lower level of unwanted energy in the one over adjacent sector.

[0126] In this case, the transmit antenna emanates a shaped beam with the kind of pattern shown in Figure 41, whereas a conventional antenna output is shown in Figure 40. As can be seen from Figure 41, the 3 dB roll off within the main beam is reduced to approximately 1 dB. This results in a reduced amount of power necessary to illuminate the edges of the sector with minimum power levels as compared with the conventional antenna. Either the center of a sector receives 3 dB excess power or the sector edge receives 3 dB to little power, depending on the point of reference when using a conventional antenna. For the shaped beam antennas the difference is only 1 dB, a substantial improvement. This has the advantage of reducing the power spillover into the next cell in a cellular system. See Figure 41. The shaped beam antenna also has very good sidelobes which result in low levels of one over adjacent sector unwanted signals.

[0127] Figure 42 depicts a sectorized antenna array 46 that emits three different beams. The first, 302, is directed down toward the ground at an angle of -1.0 degrees. The gain of the first beam 302 is 38 dB. The second, 304, is directed down toward the ground at an angle of -2.17 degrees. The gain of the second beam is 32 dB. Finally, a third beam, 306, is pointed downwards at -4.3 degrees, and has a gain of 26 dB.

[0128] Figure 43 reveals another schematic depiction of the sectorized array 46 shown in Figure 42. Each of the three beams 302, 304 and 306, is sensed by a receiver located at two miles, one mile and one-half mile away, respectively. At a distance of two miles, which is indicated by reference character 312, beam 302 (-1.0 degrees) experiences a space loss of 133 dB. At one mile, shown by reference character 310, beam 304 (-2.17 degrees) experiences a space loss of 126 dB. Beam 306 (-4.3 degrees) realizes a space loss of 120 dB at one-half mile (308).

Use of Transmitter Incorporated into the User Receiver for Weather Gain Feedback

[0129] Another characteristic offered by the present invention pertains to the installation of a very low power transmitter in each remote receiver. The transmitter may use the same antenna and local oscillator as the receiver, and in the low duty cycle mode interjects signals in the received stream in a back-channel mode.

[0130] The receive system samples the received signal strength, and when it falls below minimum levels, it sends a signal back to the node requesting additional transmit power. In this manner, a feedback loop is established to increase transmit power during period of rain.

Use of the Return Signal as the Enabling Element in an Active Public Key Private Key Encryption System

[0131] The system may also employ a return channel to carry information for an encryption system. The use of public and private keys for encryption is well known to persons skilled in the encryption arts. The present invention uses keys that can be changed at will and randomly for each individual user. The key and an acknowledgement can be conveyed back and forth between the transmit node and the user. This method has the advantage of making the code breaking process very difficult for even very inexpensive, low overhead forms of encryption.

[0132] One way to implement this encryption method is to use frequency hopping of the local oscillator on the receive and transmit system. A two or three oscillator system is used where one oscillator is providing a local oscillator signal for the radio at time $t=0$. The second oscillator is set to the next frequency, and begins to stabilize and go through the process of phase or frequency locking. The third oscillator is set to the third frequency to be used in the hopping scheme, and begins the process of stabilizing in the same fashion as the second. When the second oscillator is stabilized, the output is switched to the mixer and the first oscillator is switched away from the mixer. Switches that can toggle in a few nanoseconds are utilized to implement this method. In contrast, oscillators may take upwards of several microseconds to stabilize and lock after being set to a new frequency. The hopping frequency can be increased by the number of oscillators used. As an example, if three oscillators are used and the settling time is 6 microseconds, and the switch-over time is 10 nanoseconds, then each oscillator can be switched to a new frequency every 2 microseconds. The encryption signal tells what the hop sequence is. Unless the hopping sequence is known, an oscillator trying to follow the hopping scheme will never have enough dwell time to synch up with the signal, hence rendering its output useless. A unique code can be stored in each receiver in a digital look up table. The code can be the serial number of the receiver. This code can be a vary with the time of day or the day of the year, or may be a special code transmitted from the node at any time. The transmit signal from the receiver to the node can select from a number of look up tables stored in the receiver, and thereby request from the node a corresponding code (or key) to unlock a decryption code based on the time, day of year and the code just requested. The decryption signal be accessed only when the user key that is transmitted correlates with all three oscillators.

Use of Antenna Pattern to Provide Constant Power to Receive Locations

[0133] Another feature of the present invention concerns the use of transmitting antennas having antenna patterns that provide uniform illumination to receive locations far from the node, as well as to those that are close to the node. This is accomplished by using an antenna pattern for the transmitting antenna arrays that provides higher amounts of

gain at horizontal elevations and less gain at lower elevations. Figures 42 and 43 show that for a minus 1 degree elevation angle, the maximum range receivers at two miles are illuminated. With a -4 degree angle, the antennas illuminate a receive location that is one half mile. The -4 degree angle needs 12 dB less transmit signal than does the -1 degree angle.

Use of a Radar Absorbing Hood over the Antenna Arrays to Reduce Emissions to Satellite

[0134] Some of the bands being awarded in the millimeter wave frequencies are shared with satellite services. To maintain compatibility with the satellites, it is necessary to reduce the emissions radiating upward. Figure 44 shows sectorized antenna arrays 46 with a hood or shroud 314 positioned over them. The shroud 314 is made of a radar absorbing material, such as Emerson and Cummings Echosorb. The shroud 314 serves the function as a radar absorbing surface and reduces the upward emissions of sidelobe energy 316. This shroud 314 also serves to shield the antennas from rain and from waste products from birds.

Use of Active Cancellation and Sampled Cross Polarization Signal for Active Cancellation

[0135] The present invention also offers additional advantages when a planar array is configured so that one output delivers a signal of vertical polarization and another output delivers a signal of horizontal polarization. This configuration is illustrated in Figure 45. When the antenna is exposed to a signal which has two components of equal strength but of opposite polarities, the antenna will output two signals, one from each output, one being vertical and the other being horizontal. The signal that is vertically polarized will have predominantly a vertical signal, but there will be some horizontal signal leaking through. This unwanted horizontal signal will be less than the vertical signal, typically by 15 to 30 dB. The horizontal output of the antenna containing predominantly the horizontal signal will likewise have a small vertical component which is smaller than the desired horizontal signal by typically 15 to 30 dB.

[0136] The circuitry shown in Figure 45 samples the horizontal signal, shifts the phase angle by 180 degrees and adds this signal to the signal from the vertical output. The net effect is to cancel the unwanted horizontal leakage by another 20 to 30 dB. This technique is well known and has been used by American Nucleonics™ and the U.S. Air Force for a number of years in a different fashion. The result is an antenna with rejection from polarization and active cancellation on the order of 40 dB to 60 dB at small fractions of a beamwidth from the main beam, and with 20 to 30 dB rejection due to antenna roll off at just over one beamwidth from the main beam.

[0137] The circuit components depicted the schematic diagram 320 shown in Figure 45 comprise an antenna 326 which receives vertically and horizontally polarized signals 322 and 324. The antenna 326 produces a vertical V+ (-30dBH) and a horizontal H+ (-30dBV) output 328 and 330. The horizontal output 330 is fed to two amplifiers 332 and 334 and then to an adder 336. A coupler 338 is connected between amplifiers 332 and 334, and conveys signals through another amplifier 340 and a phase reverser 342 to an adder 344. The vertical output 328 is fed through an amplifier 346 to adder 344, which produces an output V+ (-60 dBH) 348. A coupler 350 picks up the vertical output 328 before amplifier 346, conveys them through another amplifier 352 and a phase reverser 354, and finally to adder 336, which produces an output H+ (-60dBV) 358.

[0138] The present invention offers an alternative cross polarization cancellation scheme that assumes the signals sent in the horizontal and vertical polarization have pilot carriers on each to identify them. That is, on the signals sent horizontally, there is a CW pilot carrier different from the CW pilot carrier sent with the vertically polarized signals.

[0139] Figure 46 furnishes a schematic diagram 360 of a cross-polarization cancellation scheme. The cross-polarization cancellation circuit includes an antenna 362 which produces horizontal and vertical outputs 364 and 365. The horizontal output 364 flows through a mixer 366, a filter 368, and two splitters 370 and 372. Output 374 is a horizontal signal with cancelled cross-polarization. Splitter 370 conveys a portion of the horizontal signal to a variable attenuator 376, a phase shifter 378 and a coupler 380 which directs its own output into the link which connects the two splitters 370 and 372. Splitter 372 conveys a portions of the horizontal component to a vertical pilot filter 382 which, in turn, provides an output to a controller 384 that is coupled to phase shifters 378 and 398. An oscillator 390 supplies a signal through an amplifier 388 to a splitter 386 which feeds both mixers 366 and 391.

[0140] The vertical output 365 of the antenna 362 is conducted through a splitter 391, a filter 392 and another splitter 394. The two outputs of splitter 394 are fed to a variable attenuator 396 and yet another splitter 402. The variable attenuator 396 is linked to a phased shifter 398 which is also linked to a coupler 400. Splitter 402 passes signals to both a horizontal pilot filter 404 which has an output that is fed to controller 384. Splitter 402 also provides a flow of signals to an output 406 which is a vertical component with cancelled cross-polarization 406.

[0141] The squares in Figure 46 marked "H" and "V" represent the horizontal and vertical portions of the antenna 362. In practice, the horizontal and vertical portions of the antenna 362 must be co-located in order to have the phase relations between a signal and its cross-polarized signal be as constant as possible. Additionally, the signals received from both the horizontal and vertical ports on the antenna 362 are converted down to an IF frequency to make the signal

processing simpler. The oscillator LO for both antenna ports must therefore be the same and must feed two identical mixers in an identical manner. The IF filters in each of the down converted ports must also be identical. The signals that arrive from the horizontal and vertical ports then are treated identically up until the points marked IFH and IFV.

[0142] The signals at the IFH and IFV are splits in two directions each. One portion is sent to a splitter that allows some of the signal to pass on to the output, and the other portion to be used to recover the pilot carrier of the oppositely polarized channel. This signal is used to determine the level of cancellation of the cross polarized signal.

[0143] The other direction that the IFH and IFV signal travels is to a phase shifter and then a variable attenuator. After the signal passes through the phase and amplitude correction, it travels to a directional coupler. When the phase and amplitude of this signal is adjusted to be exactly equal and in opposite phase with the cross polarized signal traveling on the other side of the coupler, then cancellation will occur in the main line output for the non cross polarized signal.

[0144] The controller 384 shown in the middle of the diagram manages the error signals (pilot carriers) and adjusts the attenuators 376 and 396 and phase shifters 378 and 398 to minimize the respective pilot carriers.

[0145] Consider, for example, that the cross polarized signal is -20 dB from the main signal. This signal is split off and detected for the controller 384. A representation of this signal comes from the opposite polarized antenna. It is not attenuated. The signal level must be attenuated by 20 dB through the action of the attenuator and the coupling level of the directional coupler. Gain therefore is not needed in this cancellation scheme for the main line correction. This feature of the invention permits antennas from adjacent sectors to be positioned over a wider range of cross-over distances extending from the sector edge more towards the center of the sector.

Video Delivery

[0146] One embodiment of the invention offers video services. The system can handle a block of 40 to 70 broadcast channels, including about 12 off-air channels, delivered in AM NTSC format for tuning at the customer's TV set. This entire block could be received on a cable-ready set without the need for a set-top box.

[0147] Additional delivery capacity would be dedicated to digital channels, containing Near Video on Demand (NVOD) and Interactive Video on Demand (IVOD) transmissions. The preferred format for these channels is 64 QAM or 16 VSB modulation, with eight digital subchannels carried in each 6 MHz of spectrum. A total of 320 digital delivery subchannels would be provided for each 100 MHz block under this approach. Of these, it is expected that 80 would initially be IVOD channels; the ratio of IVOD and NVOD will grow over time.

Block Scrambling

[0148] Wireless delivery faces a greater challenge than fiber/coax in that its signals are perceived to be more susceptible to piracy than those transmitted on wireline systems. The historical solution to this problem, as employed by MMDS wireless cable operators for many years, is to scramble each channel at the headend and use a set-top box to descramble the channel as it is selected for viewing. The same approach will work for LMDS. For operation without a set-top box, however, a different technique must be found. Ideally, it would be desirable to scramble the entire broadcast block for radio transmission, and descramble it in the NarrowBeam™ Customer Interface Unit (NCIU).

[0149] The system shown in Figure 47 employs block scrambling that relies on computer-controlled frequency hopping techniques. This approach requires that a small amount of the available spectrum be reserved for the block to be scrambled. Over time, the frequency bandpass for the block will be shifted up and down within the reserved range. Each NCIU contains a processor and a frequency synthesizer that will empower it to follow these frequency shifts as they occur.

[0150] Figure 47 is a schematic diagram 408 of a block scrambling feature, useful for reducing the possibility of unauthorized reception of wireless transmissions. The transmissions from a sectorized antenna 46 are contained in a block of spectrum 410 (shown at time= t_1) which is less than the total envelope of frequency which is available. At varying intervals the entire block is shifted up or down within the envelope, as indicated by reference character 411 (shown at time= t_2). The customer interface unit 44 tracks these shifts, adjusting its down-converter as required to maintain a constant output to a television TV or other attached device.

Descrambling

[0151] A code indicating the next frequency to be used must be distributed to all NCIUs before the change occurs. To distribute this information at lowest system overhead, the NCIUs are divided into groups based on their serial numbers. A simple example consisting of 99 groups, with codes derived from the last two digits of the serial number is shown in the diagram 416 presented in Figure 48. This drawing depicts a transmission from a sectorized antenna 46 to a customer interface unit 44. A control channel is reserved for the transmission of the code.

[0152] Each group is assigned a key, *i.e.*, a selection pattern to be used for decoding transmissions from the node. The key 418 provides the CIU control processor with the information it requires to anticipate the block frequency changes imposed on the transmission from the sectorized antenna 46. In the example shown, the key is 418, indicating that the fourth, fifth and eighth bits of the frequency code are to be selected.

5 [0153] Before changing frequency, a message containing sufficient bits to convey the desired information to all NCIUs is prepared at the node. It is transmitted on the pilot channel, which also serves to synchronize NCIU operation. At a common moment, all NCIU controllers 114 will reset their synthesizers to match the new standard. For video programs within the block, it may be necessary to perform a frame synchronization at the headend, as has been done in other services for purposes of rescrumbling.

10 *Invalidating Pirates*

[0154] Part of the plan for defeating attempts to pirate wireless transmissions include a scheme for invalidating the operation of an NCIU that has been stolen or reverse engineered to obtain free service. This can be achieved with the proposed NarrowBeam™ design, using the technique shown in Figure 49. Three general features of the design make piracy difficult:

Dependence on a software algorithm to decode the transmitted message;

Assignment of membership in a group, based on a hidden code; and

20 The ability of the individual NCIU to respond to commands sent from the sectorized antenna controller 32.

[0155] Using the third feature, a pirate unit can be invalidated when the need arises. If it is determined that a knock-off or stolen unit is stealing service, a new key can be distributed to all other members of the group in its locality. When the change is complete, the contents of the frequency code can be altered in such a way that a unit using the old key will no longer be able to determine the correct frequency. As a convenient means of suspending a legitimate unit for non-payment of bills, a code can be transmitted to the NCIU that will make it incapable of decoding any frequency information until it is replaced.

[0156] Figure 49 furnishes a diagram 422 which shows a sectorized antenna 46 transmitting a new key 424 to a pirate unit 426.

30 *Interdiction*

[0157] The descrambled block will leave the NCIU in clear form, ready for connection to a cable-ready television. It is clearly mandatory, however, to be able to withhold specific services from the customer in order to collect a monthly subscription charge or a one-time payment for a pay-per-view event. Ideally, it should be possible to enable or interdict any channel at any time, on command from the node controller 32.

[0158] Figure 50 exhibits a diagram 428 shows how channel interdiction could be accomplished using the basic NarrowBeam™ System design. An interdict table is transmitted to each NCIU on startup, and again whenever any service changes are made. The NCIU controller 114 cycles semi-continuously through the channels of the broadcast block, excluding any that form part of the basic service package. When it discovers a channel that should be blocked, it causes a burst of noise to be injected into that frequency band. By repeating this positive interdiction procedure at frequent enough intervals, reception should be effectively disrupted. The duty cycle for this function can be determined through laboratory testing.

[0159] With this combination of feature to provide block scrambling and channel interdiction, it will be possible to accomplish the goal of providing secure, flexible service without a set-up box STB. Some additional cost would be incurred to implement this system, as opposed to one providing pure bandpass delivery. The incremental cost would be considerably below the cost of providing a set-top unit. Operational costs should also be significantly reduced.

[0160] If a set-top box STB is present, or if an alternative means can be found to identify the channel requested at the TV set, additional functionality can be obtained. Given this knowledge, for example, interdiction can be imposed on a set-by-set basis, rather than for an entire household at a time. Likewise, interdiction can become more creative, offering the viewer, for example, an opportunity to subscribe on the spot to a blocked program, rather than just injecting noise into the channel.

[0161] Figure 50 depicts the use of a customer interface unit 44 to prevent the unauthorized reception of specific transmissions by specific customers. Transmissions 430 from the sectorized antenna 46 are received at the CIU antenna 432 and down-converted into a block containing all the original channels of information 434. To prohibit the receipt of certain channels, *e.g.*, pay-per-view TV programs not subscribed to by the customer, the CIU controller 436, 114 examines an interdict table 438 transmitted periodically by the node controller 32 over the control channel. If a channel is indicated as appropriate for interdiction, the CIU controller 114, 436 injects noise into that channel 440 as it

emerges from the unit.

Advanced Modulation Schemes

- 5 [0162] The NarrowBeam™ System will be capable of accommodating spectrally efficient modulation schemes such as 64 QAM and 16 VSB.

Single-Channel Output

- 10 [0163] The delivery system described above assumes that a tuning device of some sort is available for isolating a single channel from the output of the NCIU receiver. For television service this is an appropriate assumption, and the output from the NCIU receiver should be a passband containing multiple channels. For other services, however, it may be useful to include in the NCIU the ability to tune to a selected channel of a bandwidth suitable for a connected device such as a computer or telephone.

Back Channels

- 15 [0164] Two types of return channel can be considered for the LMDS system. For applications with light duty cycles, such as program selection, a shared channel will be the most economic approach. Such a channel could be transmitted through the same antenna used to receive signals from the node. For interactive use, as well as voice or data services, a dedicated channel will be required. However, by assigning some additional functionality to the node it should be possible to take advantage of the fact that less than 100% of these channels will be connected at any given time. Using a polling procedure or equivalent, the node controller 32 can be notified by an NCIU of the desire of a customer to use one of a pool of dedicated channels. Through a response directed to that unit, its controller 114 can be required to tune to a selected channel for its transmission. At the end of the call, the channel is returned to the pool of available resources. This procedure is illustrated in Figure 51.

- 20 [0165] Figure 51 is a diagram 442 that illustrates the use of the present invention to perform local switching functions. This feature maximizes the utilization of the available spectrum. The node controller 32 supervises this function through an interchange of information with customer interface units 44 over the control channel 444 included in the transmitted block 442. To receive or transmit information, the CIU controller 114 requests a channel appropriate for its attached device 450. If this capacity is available, the controller 32 identifies a channel 446 to the CIU controller 114, which proceeds to tune its input or output frequency to that band.

INDUSTRIAL APPLICABILITY

- 35 [0166] The Sectorized Multi-Function Communication System described above will provide a wide variety of communication services, including two-way broadband links, selectable video-on-demand, wireless cable services and enhanced audio programming.

CONCLUSION

- 40 [0167] Although the present invention has been described in detail with reference to particular preferred and alternative embodiments, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the Claims that follow. The various hardware configurations that have been disclosed above are intended to educate the reader about preferred and alternative embodiments, and are not intended to constrain the limits of the invention or the scope of the Claims. The *List of Reference Characters* which follows is intended to provide the reader with a convenient means of identifying elements of the invention in the Specification and Drawings. This list is not intended to delineate or narrow the scope of the Claims.

LIST OF REFERENCE CHARACTERS

[0168]

- 55 10A Sectorized Multi-Function Communication System - One-Way Embodiment
 10B Sectorized Multi-Function Communication System - Two-Way Embodiment
 11 Sectorized cell
 12 First sector

	14	Second sector
	15A	Transmitting antenna array
	15B	Transmitting and receiving antenna array
	16	Transmitting antenna
5	17A	Transmitting antenna array
	17B	Transmitting and receiving antenna array
	18	Transmitting antenna
	19	Beamwidth
	20	First receiver
10	22	Second receiver
	24T	Transmitting antenna
	24R	Receiving antenna
	26T	Transmitting antenna
	26R	Receiving antenna
15	28	First transceiver
	30	Second transceiver
	32	Controller
	34	Schematic depiction of selective coverage to geographic areas
	36	Illustration of selective bandwidths for sectors having different communications requirements
20	38	Residential sector
	40	Commercial sector
	42	Schematic depiction of line of sight requirements
	44	Customer Interface Unit
	46	Sectorized antenna
25	47	Square planar antenna array
	48	Substrate
	49	Feed detail
	50	Rectangular planar antenna array
	52	First 1,000 MHz bandwidth block usage diagram
30	54	Second 1,000 MHz bandwidth block usage diagram
	56	Third 1,000 MHz bandwidth block usage diagram
	58	System overview
	60	Network
	62	Sectorized hub design
35	64	Outgoing signals
	66	Incoming signals
	68	Dedicated network server
	71	Block diagram showing switching and transmission
	70	Point-to-point microwave links
40	72	NarrowBeam™ antenna
	73	Signals from TV headend
	74	Signals from video server
	75	Signals from PSTN
	76	Switch circuitry
45	77	Fixed block output
	78	Switched channel output
	79	Fixed channel output
	80	Upconverters
	81	Diagram depicting requests for service
50	82	Node transmitter
	83	Diagram showing dual-frequency system
	84	Off-hook signal
	85	Up/Down conversion
	86	Dedicated channels
55	87	Node receiver
	88	One-way transmission
	89	Demultiplexer
	90	Two-way transmission

91	Cable television network signal distribution system
92	Switch
93	Customer terminals
94	Telephone network signal distribution system
5 95	Narrowbeam network extension system
96	Server
97	Electronic switching system
98	Dedicated fiber links
99	Fiber trunks
10 100	NarrowBeam™ nodes
101	Level 1 system
102	LMDS transmission block
103	Interface modules
104	Up converter
15 105	Multiplexer
106	Transmit array
107	Customer interface unit receiving antenna ray
108	Level 2 system
109	Node controller
20 110	Level 3 system
111	Receive array
112	Shared return channel
113	Down converter
114	Customer interface unit controller
25 116	CIU receive antenna
117	CIU transmit antenna
118	Level 4 system
120	Level 5 system
122	Level 6 system
30 124	Single-family residence
125	Residential antenna
126	Multiple-dwelling apartment
128	Channel allocation diagram
130	Standard broadcast channels
35 132	Additional broadcast channel block
134	Additional broadcast channel block
136	Premium broadcast channel
138	Interdict table
140	Node block diagram
40 142	Fiber trunks
144	Optical/electrical converter
146	Signal/control link
148	Independent up- and down-converters
150	Frequency division modulation multiplexer/up-converter
45 152	Transmitter
154	Receiver
156	Frequency division modulation demultiplexer/down-converter
157	Electrical/optical converter
158	Switch
50 160	Sector 1 demultiplexer
161	Single channel buses
162	Sector 2 multiplexer
163	Switches
164	Sector 2 demultiplexer
55 166	Sector 2 multiplexer
168	Sector 3 demultiplexer
170	Sector 3 multiplexer
172	POP interface

	174	POP demultiplexer
	176	Variable up-converters
	178	Switches
	180	Variable down-converters
5	182	POP multiplexer
	184	Alternate point-to-point routing diagram
	186	City center
	188	Diagram showing how links are tailored to traffic density
	190	Single-user transceiver block diagram
10	192	Roof top
	194	Office within building
	196	Transceiver
	198	Antenna
	199	Antenna
15	200	Local oscillator
	202	Modem
	204	Fiber interface in transceiver
	206	Control circuitry
	208	DC power
20	210	Fiber interface in building
	212	Coder/decoder
	214	Device
	216	Multi-user transceiver block diagram
	218	Demodulator No. 1
25	220	Demodulator No. 10
	222	Control circuitry
	224	Modulator No. 1
	226	Modulator No. 10
	228	Fiber optic interface
30	230	Fiber optic interface in building
	232	Half duplex device
	234	Full duplex device
	236	Wait state diagram
	238	Control channel
35	240	Switch
	242	Control
	244	Buffer
	246	Device
	248	Transmit diagram
40	250	Data channel
	258	Hexagonal array
	261	Antenna Array No. 1
	262	Antenna Array No. 2
	263	Antenna Array No. 3
45	264	Antenna Array No. 4
	265	Antenna Array No. 5
	266	Antenna Array No. 6
	271	Sector 1
	272	Sector 2
50	273	Sector 3
	274	Sector 4
	275	Sector 5
	276	Sector 6
	284	Vertically polarized beam from Antenna Array 4
55	285	Horizontally polarized beam from Antenna Array 5
	286	Vertically polarized beam from Antenna Array 6
	294	Receive antenna for Sector 4- Vertically polarized
	295	Receive antenna for Sector 5- Horizontally polarized

	296	Receive antenna for Sector 6- Vertically polarized
	298	Conventional antenna output
	300	Output with beam shaping
	302	Beam at -1.0 degrees elevation
5	304	Beam at -2.17 degrees elevation
	306	Beam at -4.3 degrees elevation
	308	Receiver position at 1/2 mile
	310	Receiver position at one mile
	312	Receiver position at two miles
10	314	Shroud
	316	Undesired side-lobe energy
	318	Desired transmitted energy
	320	Antenna signal processing block diagram
	322	Vertically polarized signals
15	324	Horizontally polarized signals
	326	Antenna
	328	Vertical output
	330	Horizontal output
	332	Amplifier
20	334	Amplifier
	336	Adder
	338	Coupler
	340	Amplifier
	342	Phase reverser
25	344	Adder
	346	Amplifier
	348	Adder output
	350	Coupler
	352	Amplifier
30	354	Phase reverser
	356	Adder input
	358	Adder output
	360	Cross polarization cancellation circuitry block diagram
	362	Antenna
35	364	Horizontal signal
	365	Mixer
	366	Mixer
	368	Filter
	370	Splitter
40	372	Splitter
	374	Horizontal signal output
	376	Variable attenuator
	378	Phase shifter
	380	Potentiometer
45	382	Vertical pilot filter
	384	Controller
	386	Splitter
	388	Amplifier
	390	Oscillator
50	391	Mixer
	392	Filter
	394	Splitter
	396	Variable attenuator
	398	Phase shifter
55	400	Potentiometer
	402	Splitter
	404	Horizontal pilot filter
	406	Vertical signal output

408	Block scrambling diagram
410	Transmitted block at Time 1
411	Transmitted block at Time 2
416	Descrambling block diagram
5 418	Key
420	Premises unit
422	Diagram showing method of invalidating pirates
424	New key
426	Pirate unit
10 428	Diagram showing channel interdiction
430	Radio frequency signal
432	Customer premises unit
434	Downconverted channels
436	Controller
15 438	Interdict table
440	Interdicted channels
442	Diagram showing local switching function
444	1,000 MHz block
446	Pool of dedicated channels
20 448	Customer premises
450	Television
AM	Amplitude modulation
B	Buildings
CIU	Customer interface unit
25 dB	Decibel
DEMUX	Demultiplexer
ESS	Electronic switching system
FD	Full duplex
FDM	Frequency division modulation
30 FL	Fiber link
FM	Frequency modulation
GHz	Giga Hertz
HD	Half duplex
IF	Intermediate frequency
35 IIU	Interactive interface unit
IVOD	Interactive video on demand
KBPS	Kilo bits per second
KHz	Kilo Hertz
LMDS	Local multi-point distribution system
40 M	Mountains
MBPS	Mega bits per second
MHz	Mega Hertz
MUX	Multiplexer
N	Node
45 NCIU	Narrowbeam customer interface unit
NVOD	Near video on demand
P	Pole
PC	Personal computer
POP	Point of presence
50 PSTN	Public switched telephone network
RA	Remote areas
RC	Rain clouds
RF	Radio frequency
STB	Set-top box
55 TP	Telephone
TR	Trees
TV	Television
TWT	Traveling wave tube

Claims

1. A communications system (10A, 10B) comprising a plurality of cells (11), each cell comprising a substantially centrally-located receiving and/or transmitting antenna member surrounded by a plurality of substantially sector-shaped regions (12, 14, 38, 40) extending out to the edge of the cell from the antenna member, the antenna member comprising a plurality of circumferentially distributed directional antenna elements (15A, 17A, 15B, 17B), each antenna element being arranged to communicate only with receivers (20, 22, 28, 30) located within a single one of said sector-shaped regions, characterized in that the sector angles of the sector-shaped regions (12, 14, 38, 40) lies within the range 2 degrees to 15 degrees.
2. A communications system according to claim 1 wherein each antenna element comprises an array of radiating elements and means for distributing power to the individual radiating elements so that the centre-most radiating elements radiate more power than the radiating elements at the periphery of the array.
3. A communications system according to claim 2 wherein each antenna element has a main beam roll off of approximately 1 dB.
4. A communications system according to any preceding claim wherein the elements (15B) directed to a first sector-shaped region (40) have a first frequency bandwidth and the elements (17B) directed to a second sector-shaped region (38) have a second frequency bandwidth that is wider than the first frequency bandwidth.
5. A communications system according to any preceding claim wherein each receiver (20, 22) incorporates a customer interface unit controller (114) having means for performing cross-connection switching functions on incoming signals.
6. A communications system according to claim 1 wherein said receivers process signals to perform active cancellation.
7. A communications system according to claim 1 wherein the antenna member comprises a controller (108) which monitors output power levels supplied to each sector-shaped region and transmits a warning upon detection of unsatisfactory operation; and/or performs block scrambling of signals transmitted by the antenna member using frequency hopping; and/or inhibits the provision of selected signals to selected receivers (20, 22).
8. A method of communicating including communicating between a plurality of circumferentially distributed directional antenna elements (15A, 17A, 15B, 17B) forming a substantially centrally-located receiving and/or transmitting antenna member of a cell and, and thereby defining a plurality of substantially sector-shaped regions (12, 14, 38, 40) extending out to the edge of the cell from the antenna member, each antenna element communicating only with receivers (20, 22, 28, 30) located within a single one of said sector-shaped regions, characterized by transmitting from each antenna element a beam having a width defining the sector angles of the sector-shaped regions (12, 14, 38, 40) within the range 2 degrees to 15 degrees.
9. A method of communicating according to claim 8 further characterized by providing each antenna element with an array of radiating elements and distributing power to the individual radiating elements so that the centre-most radiating elements radiate more power than the radiating elements at the periphery of the array.
10. A method of communicating according to claim 9 further characterized by transmitting a beam from each antenna element having a main beam roll off of approximately 1 dB.
11. A method of communicating according to claim 8, 9 or 10 further characterized by directing a beam from a first antenna element (15B) to a first sector-shaped region (40) having a first frequency bandwidth and directing a beam from a second antenna element (17B) to a second sector-shaped region (38) having a second frequency bandwidth that is wider than the first frequency bandwidth.
12. A method of communicating according to claim 8, 9, 10 or 11 further characterized by performing cross-connection switching functions on received signals at each receiver (20, 22).
13. A method of communicating according to claim 8 further characterized by performing active cancellation on received signals at each receiver (20, 22).

14. A method of communicating according to claim 8 further characterized by [the antenna member comprises a controller (108) which] monitoring output power levels supplied by the antenna member to each sector-shaped region and transmitting a warning upon detection of unsatisfactory operation.

5 15. A method of communicating according to claim 8 further characterized by performing block scrambling of signals transmitted by the antenna member using frequency hopping.

16. A method of communicating according to claim 8 further characterized by inhibiting the provision of selected signals to selected receivers (20, 22).

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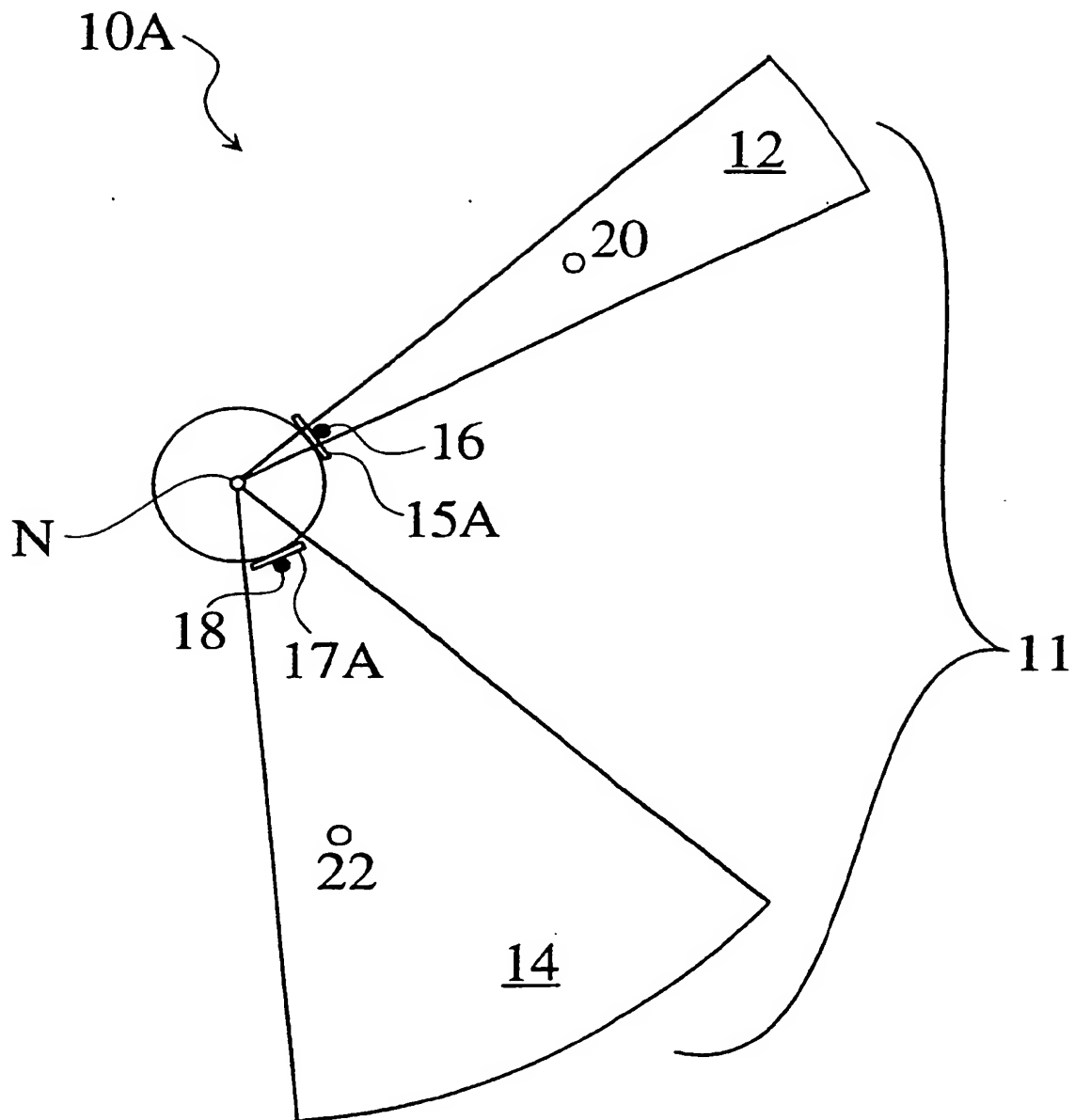


Fig. 1

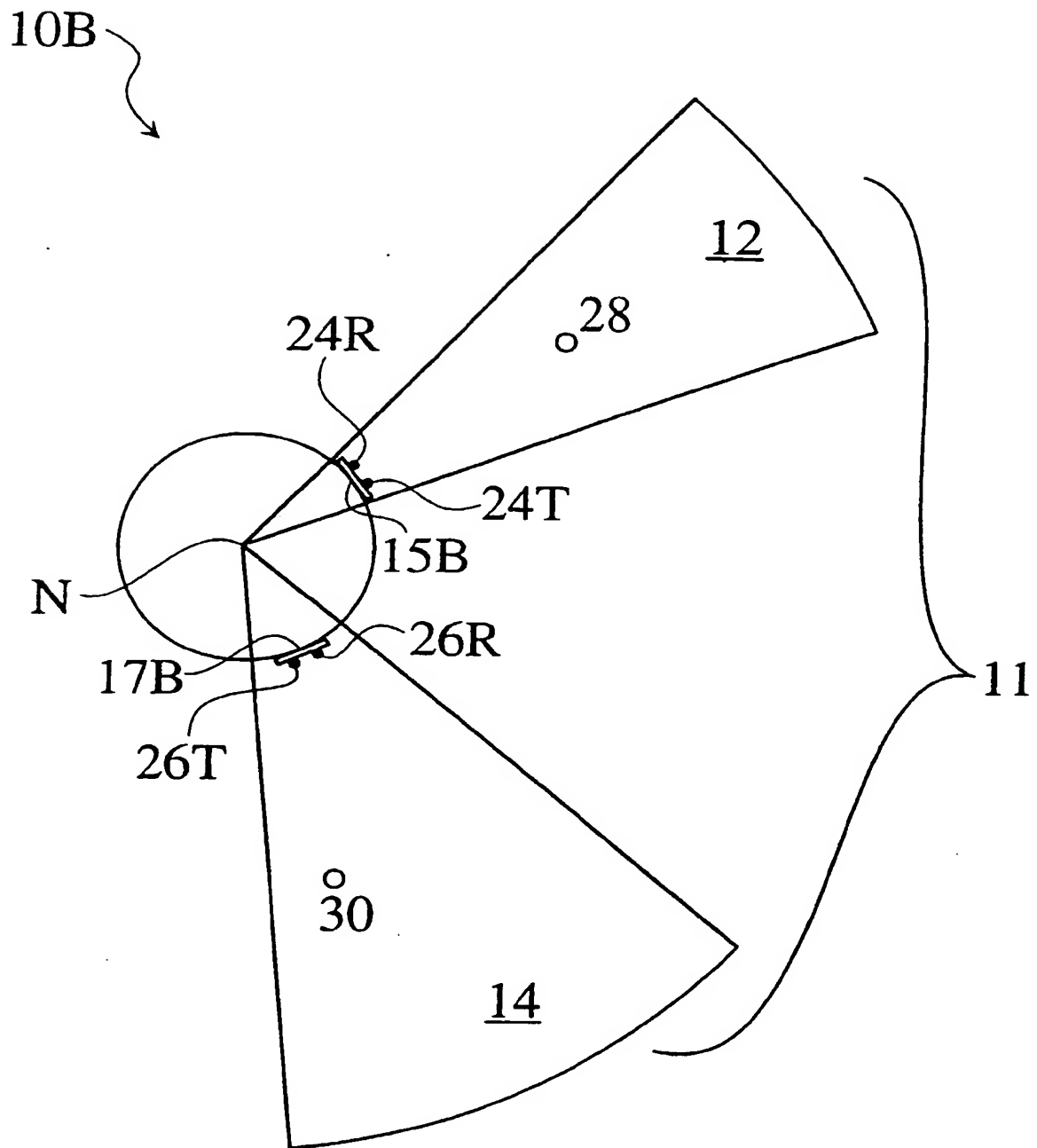
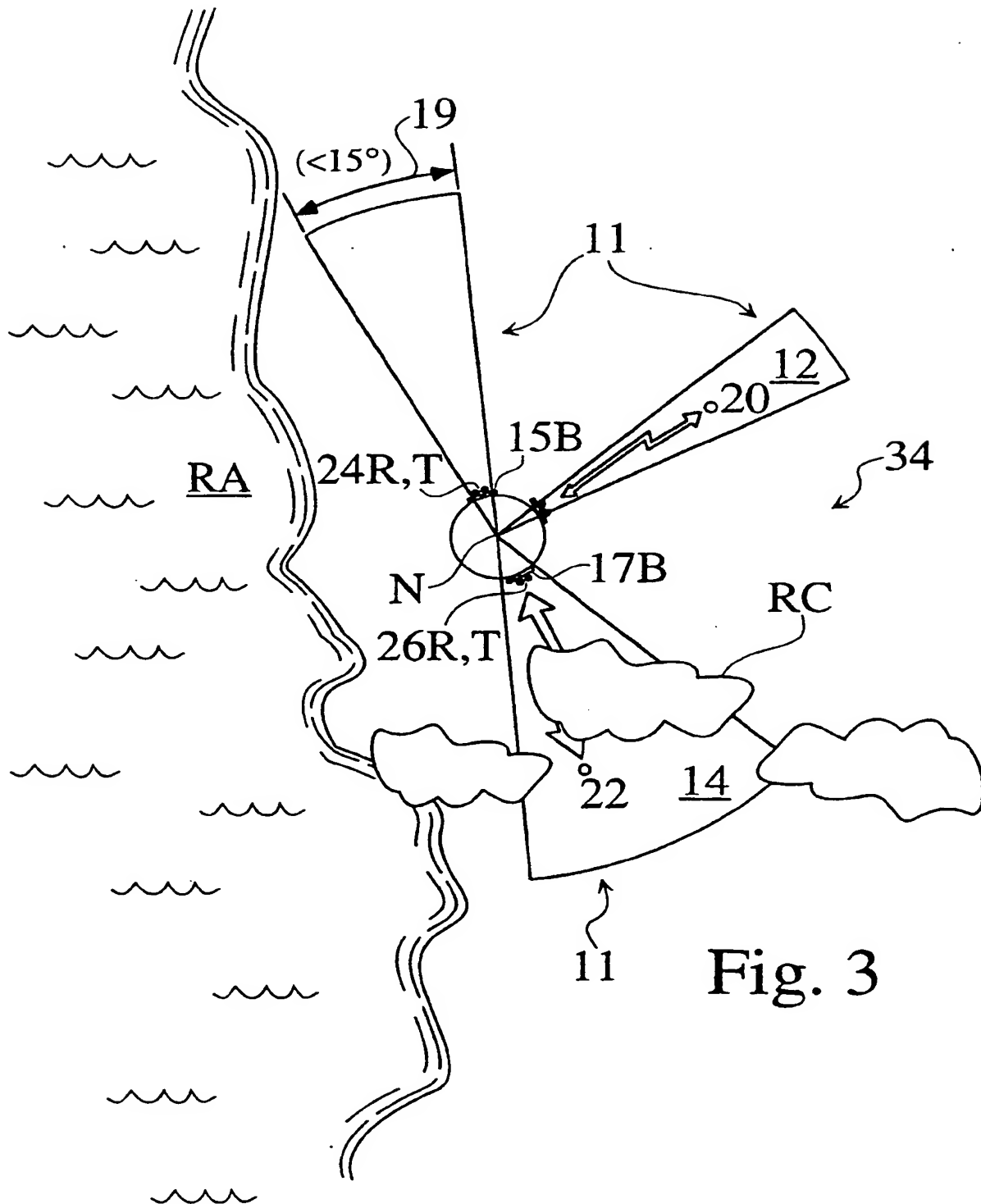


Fig. 2



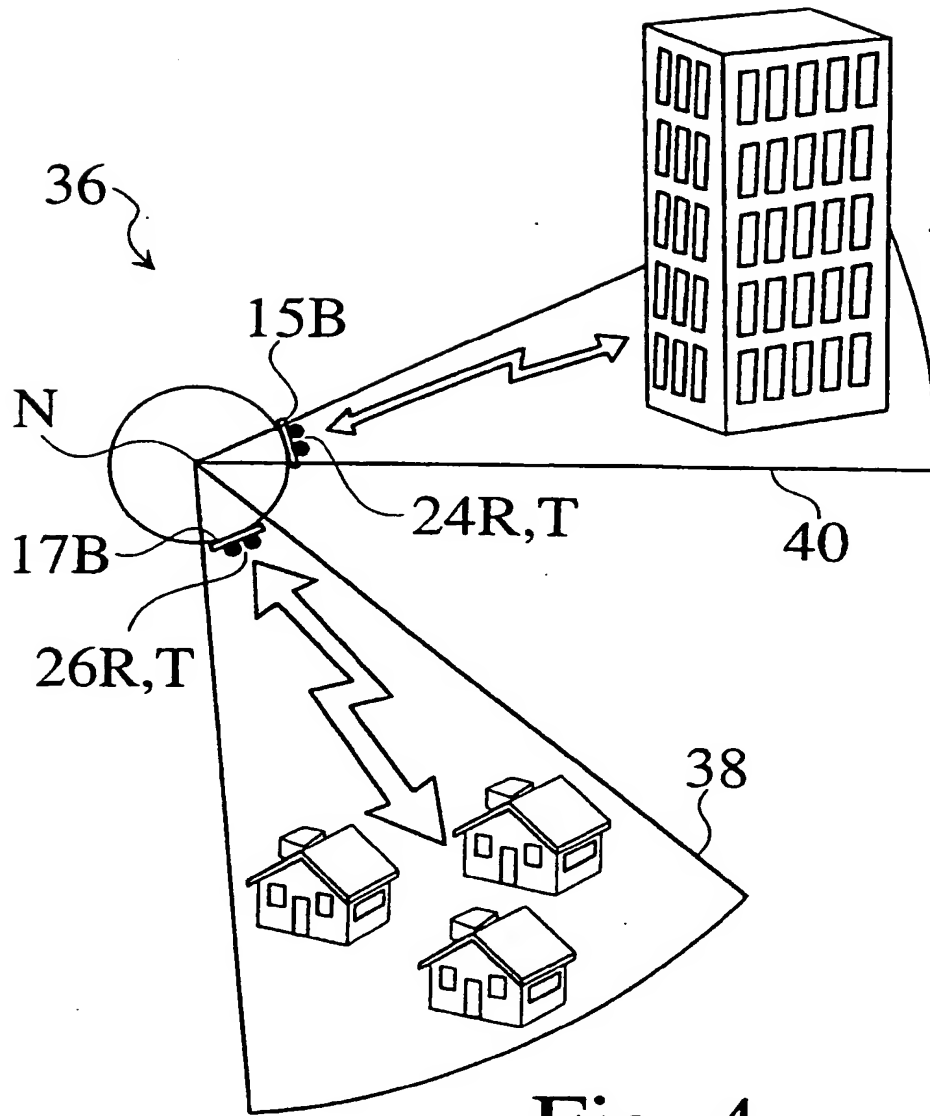
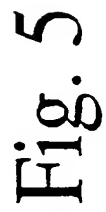


Fig. 4



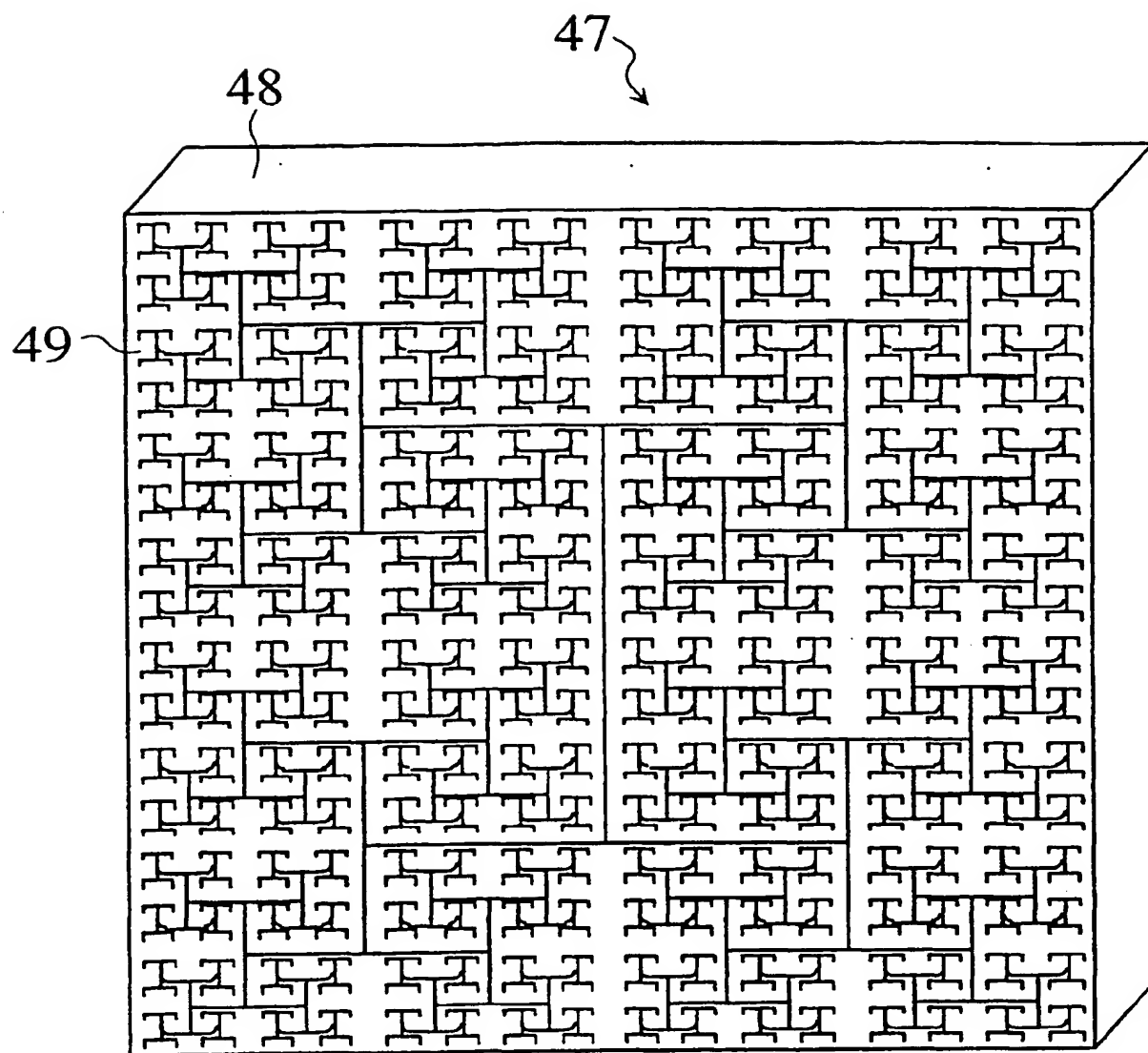


Fig. 6

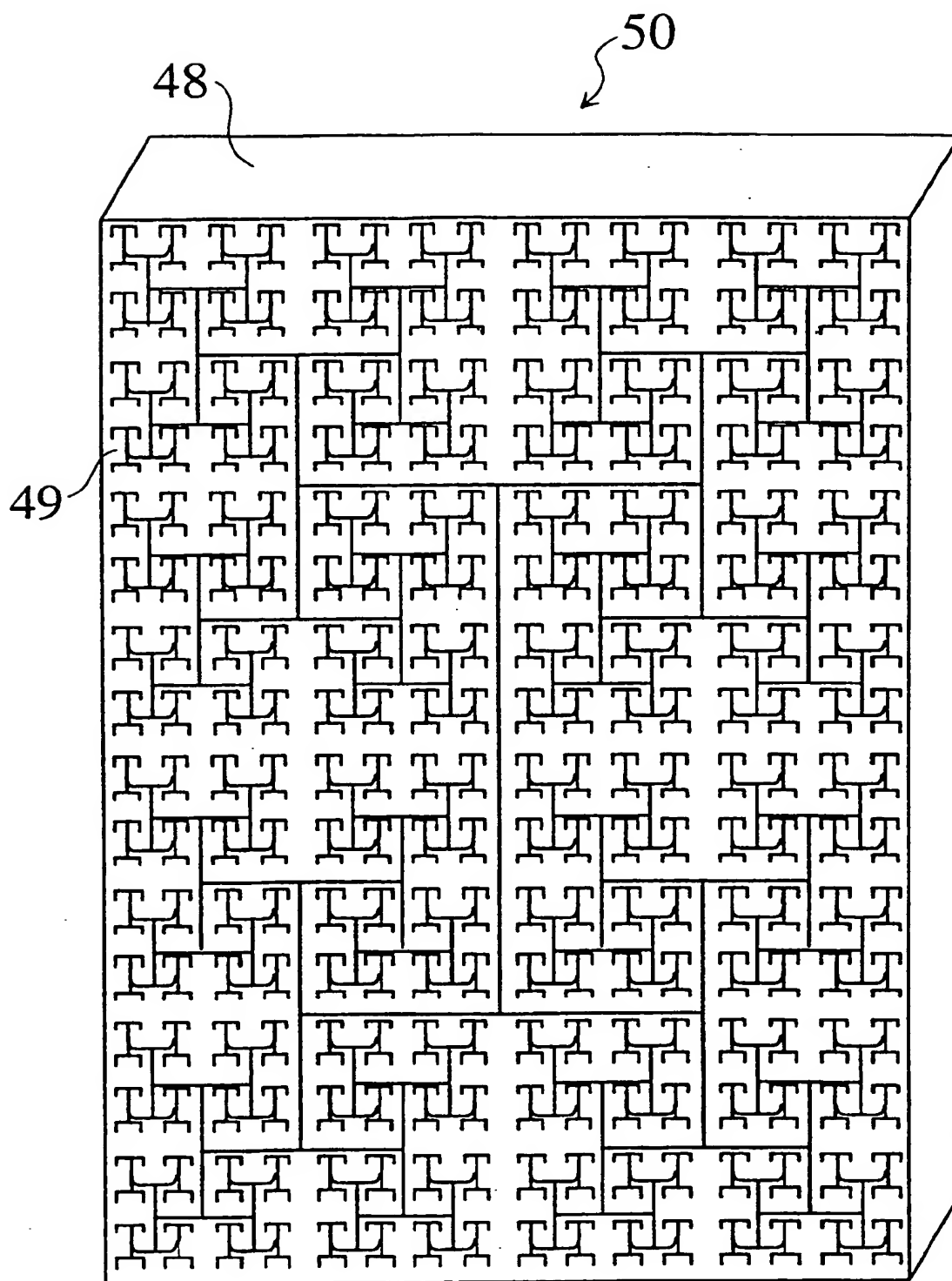


Fig. 7

AM TV PLUS DIGITAL CHANNELS	
AM TV	→
DIGITAL TV	→
SELECT / CONTROL	↔

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Fig. 8

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FM TV PLUS DIGITAL CHANNELS	
FM TV	→
DIGITAL TV	→
BROADBAND DATA	↔
SELECT / CONTROL	↔

Fig. 9

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ALL DIGITAL CHANNELS	
DIGITAL TV	→
T1 VOICE	↔
T3 VOICE	↔
SELECT / CONTROL	↔

Fig. 10

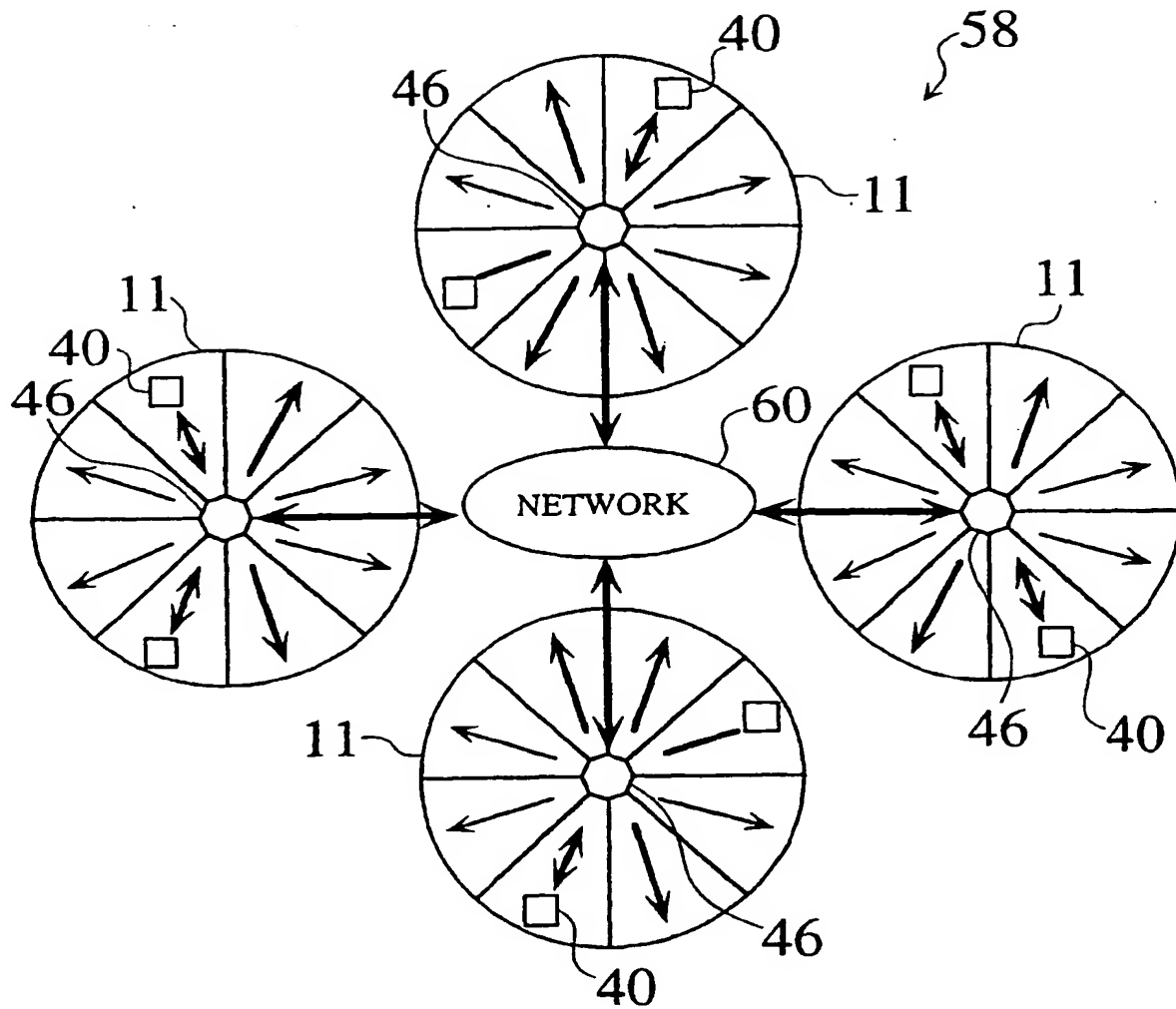


Fig. 11

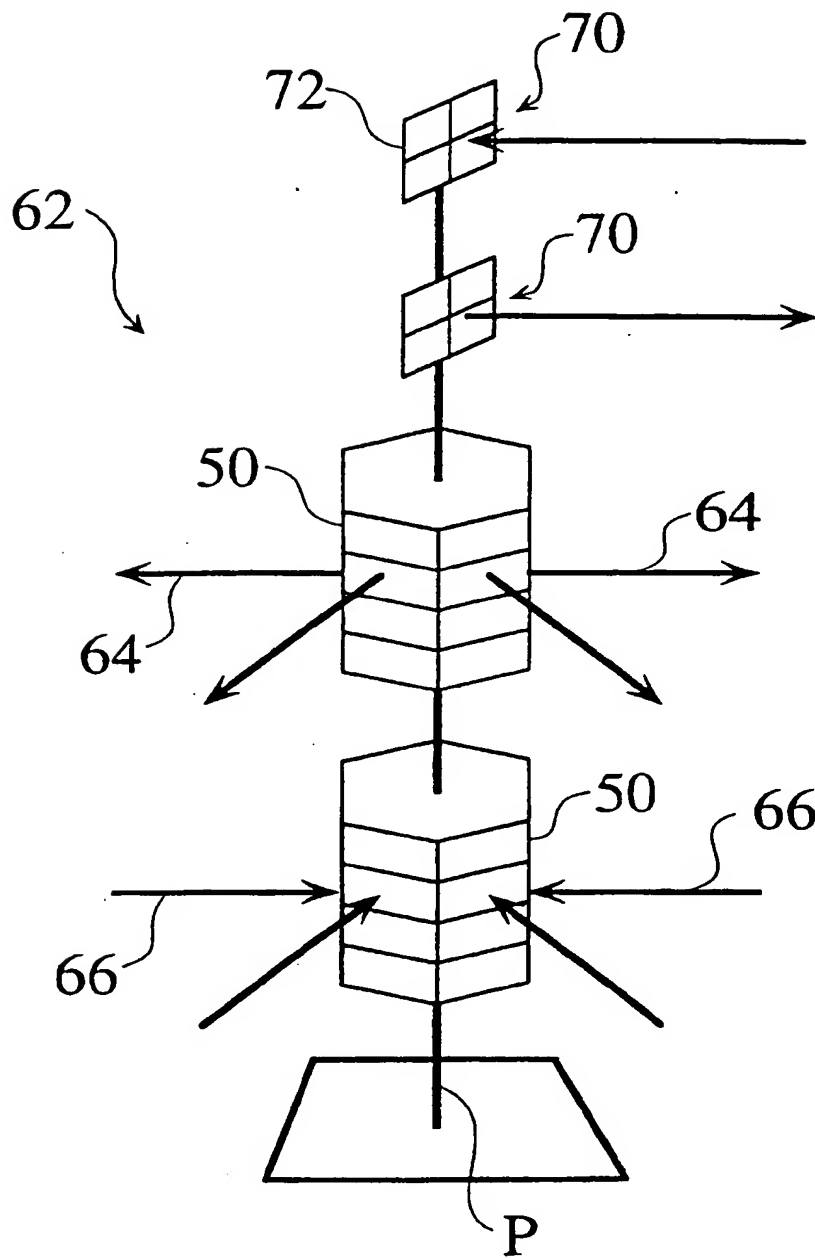


Fig. 12

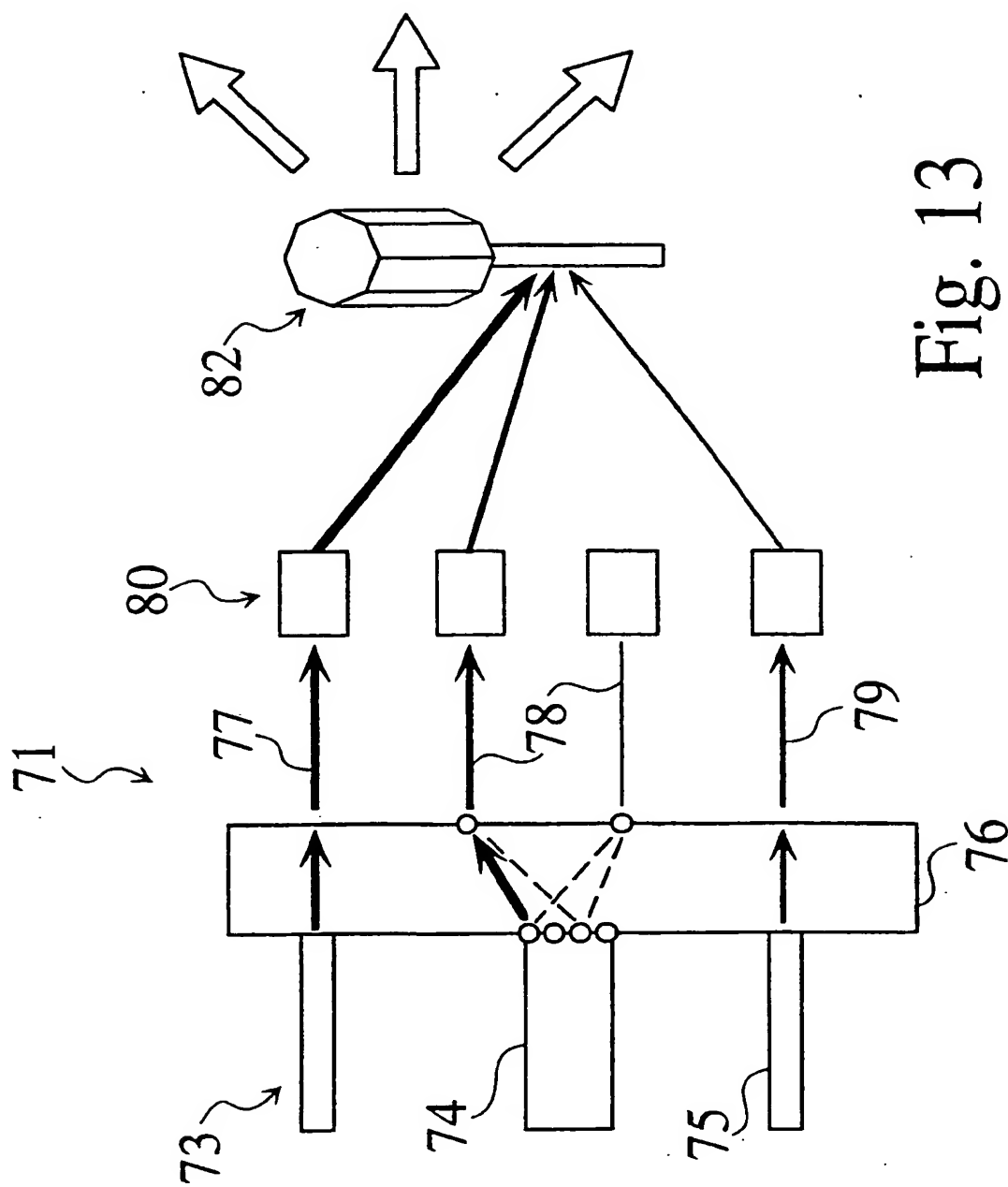


Fig. 13

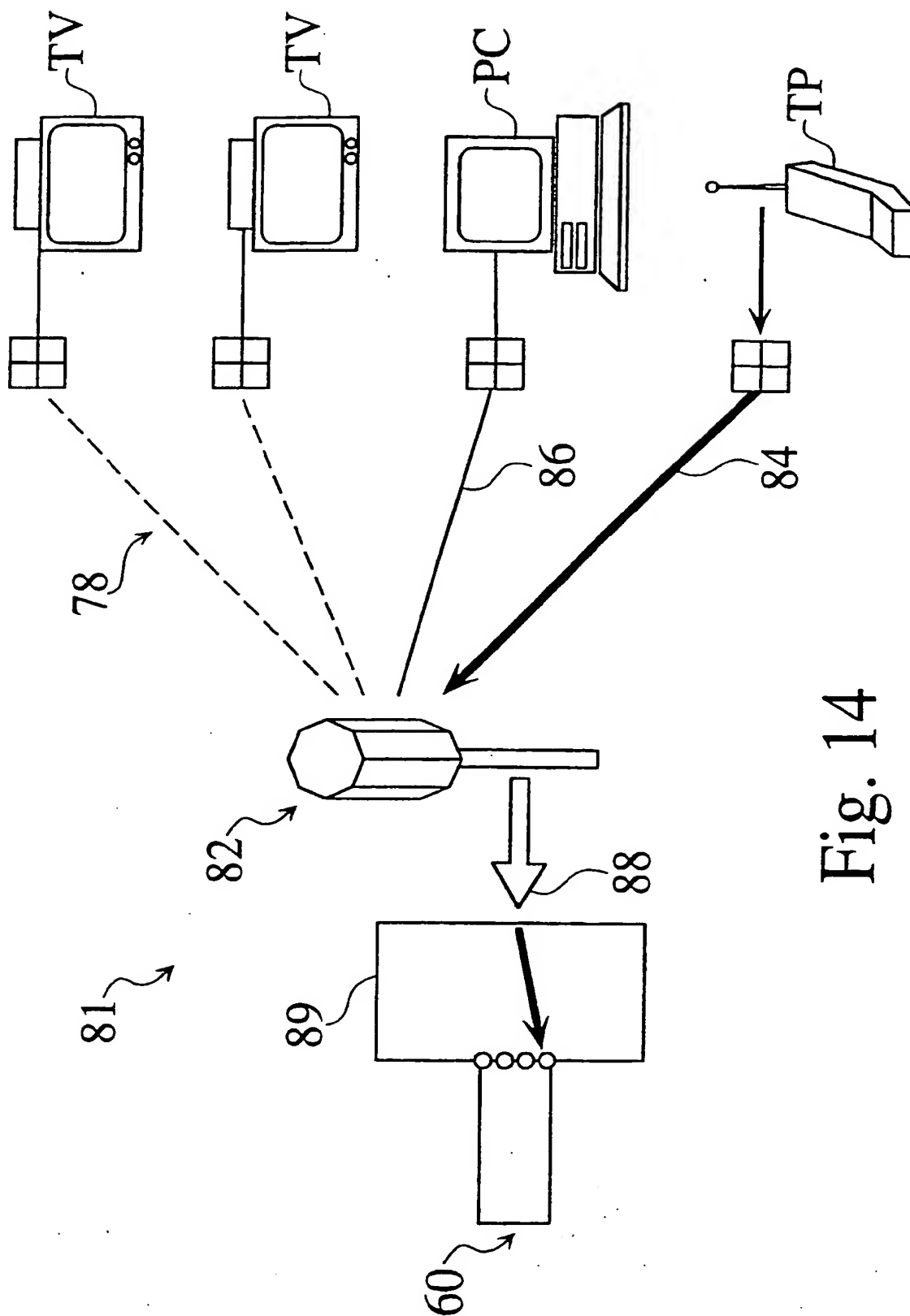


Fig. 14

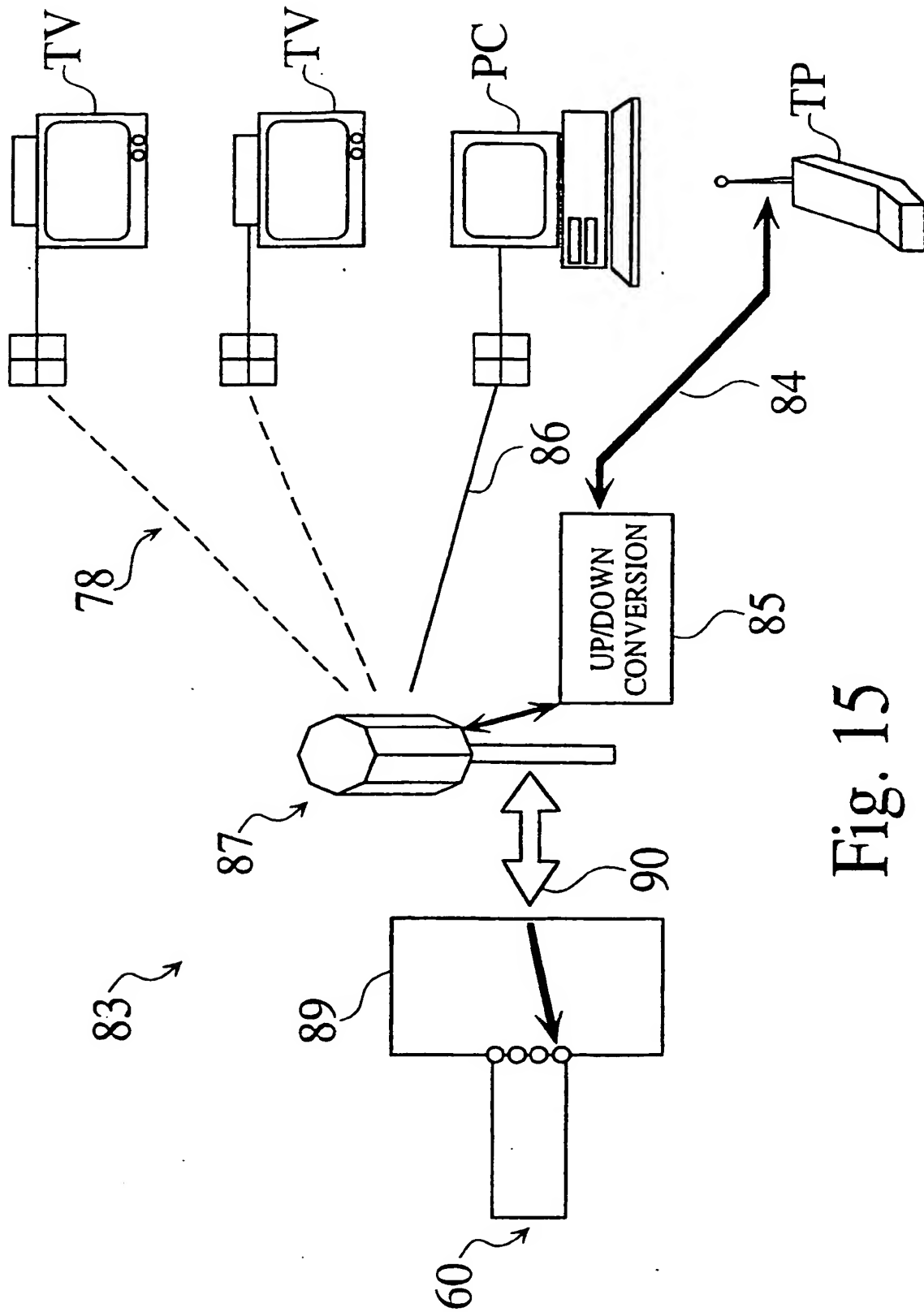


Fig. 15

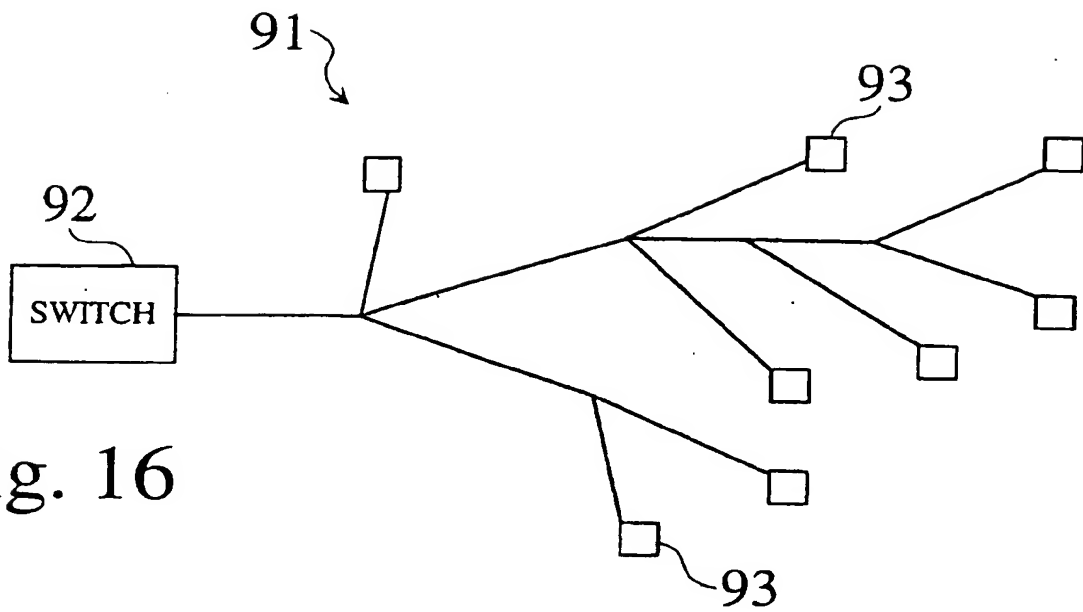


Fig. 16

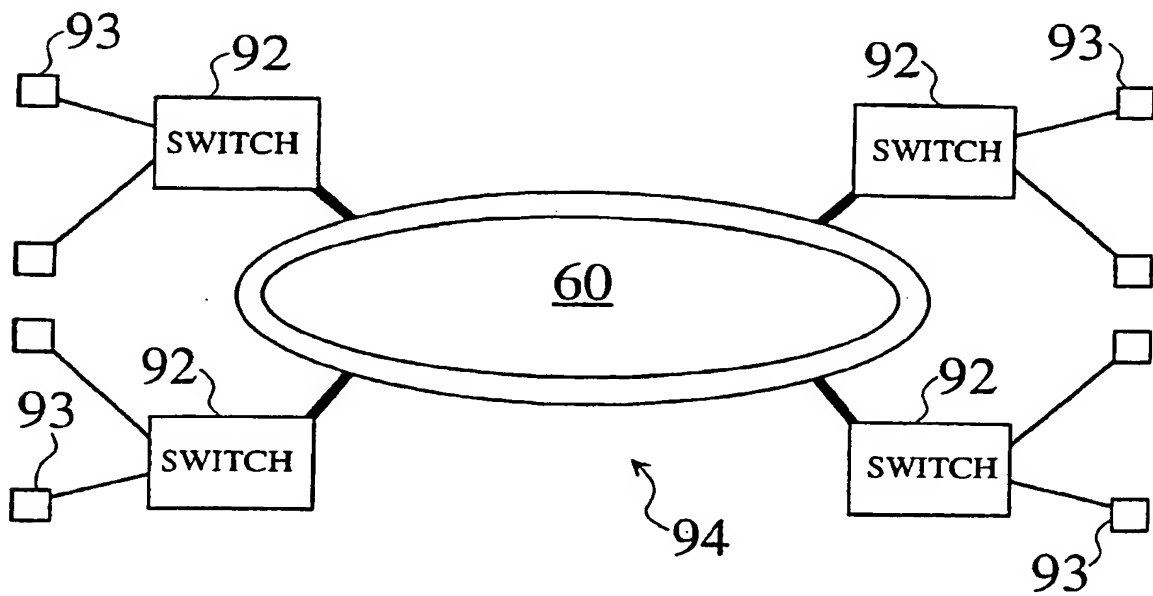


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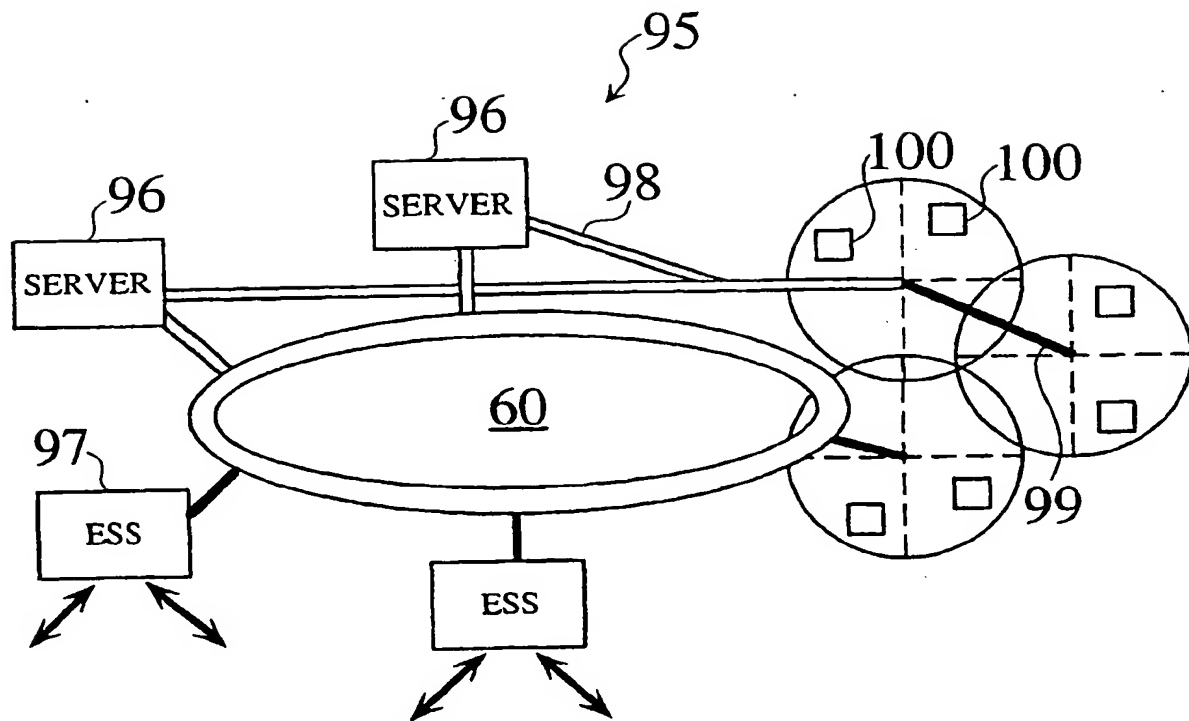


Fig. 18

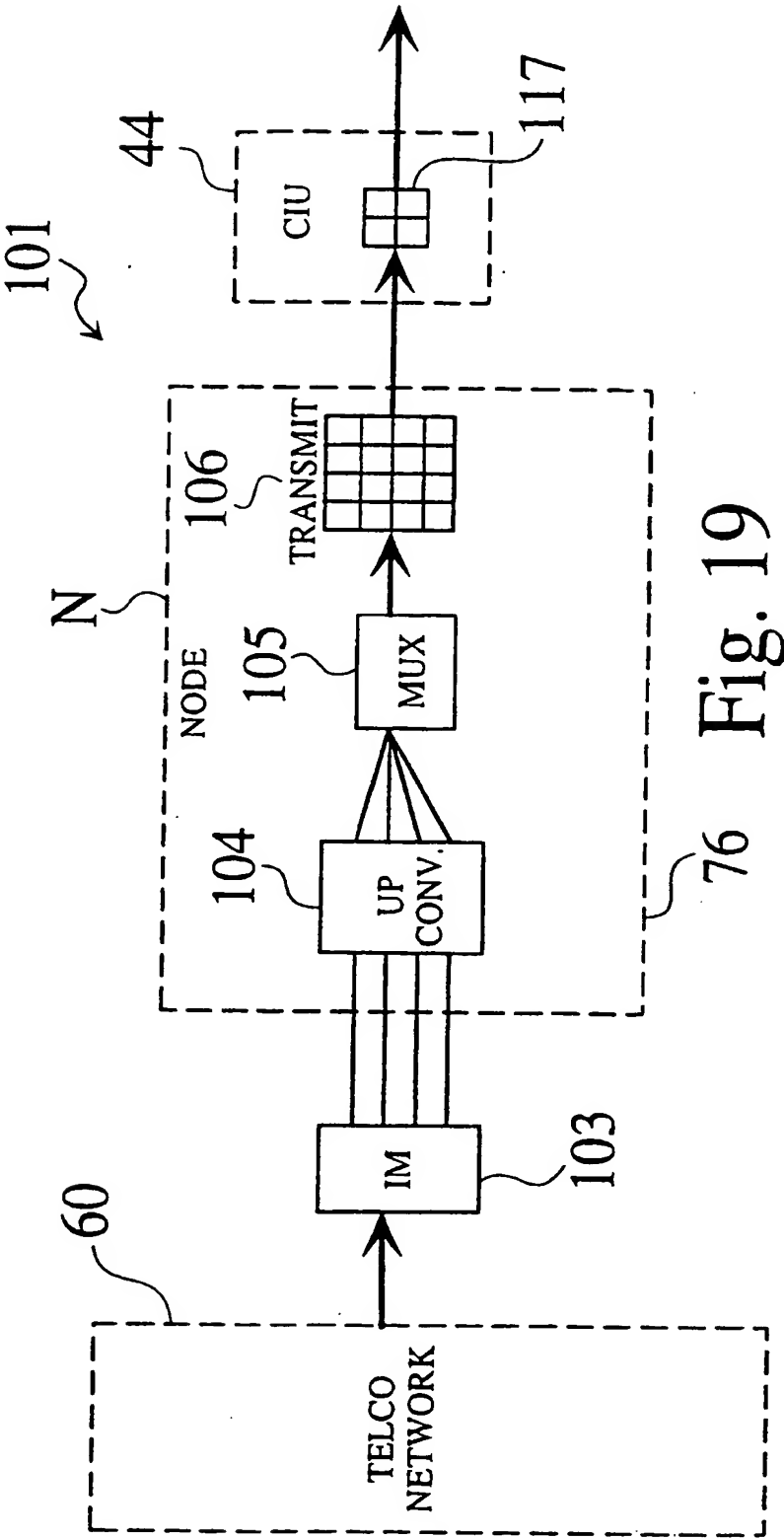
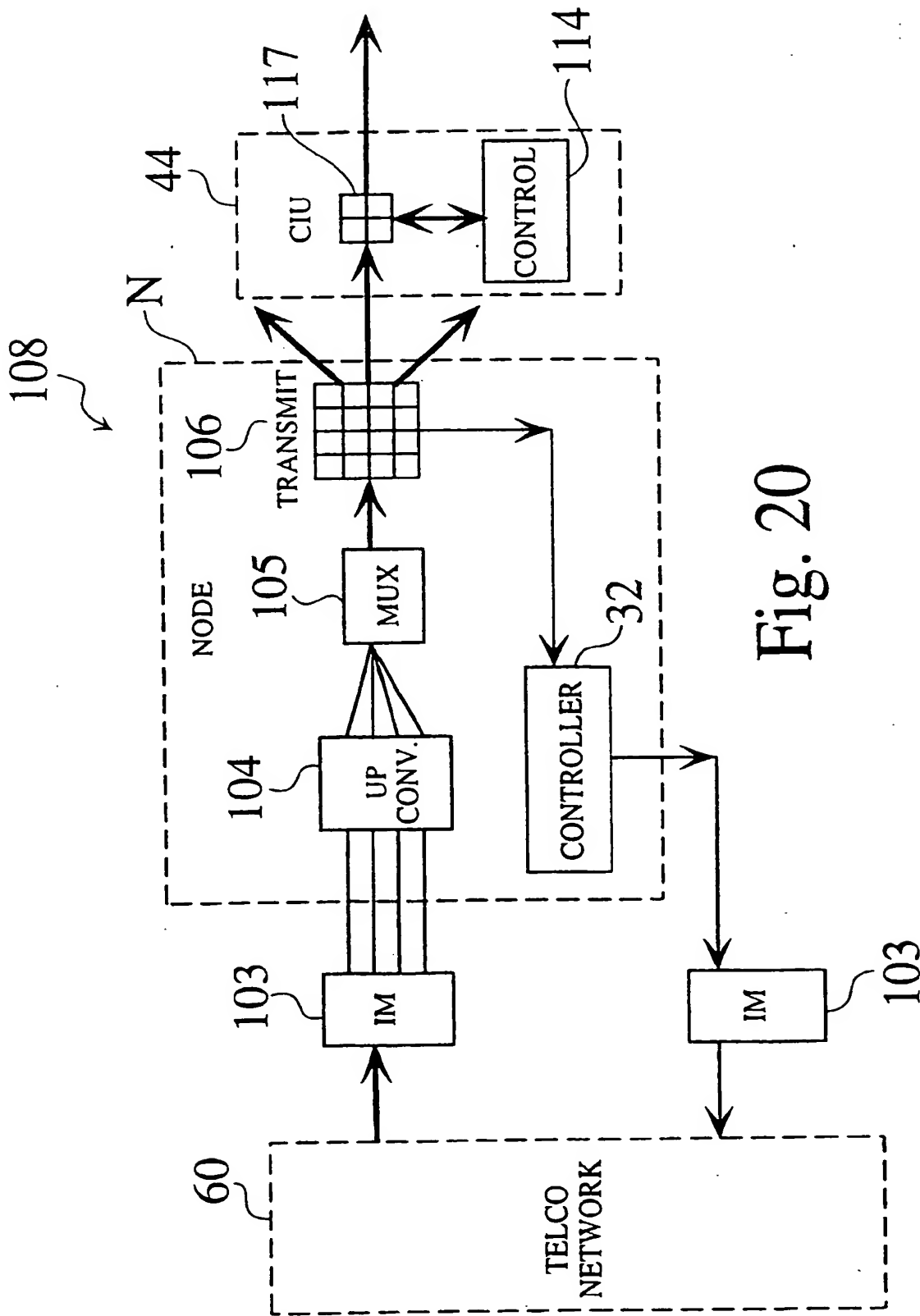


Fig. 19



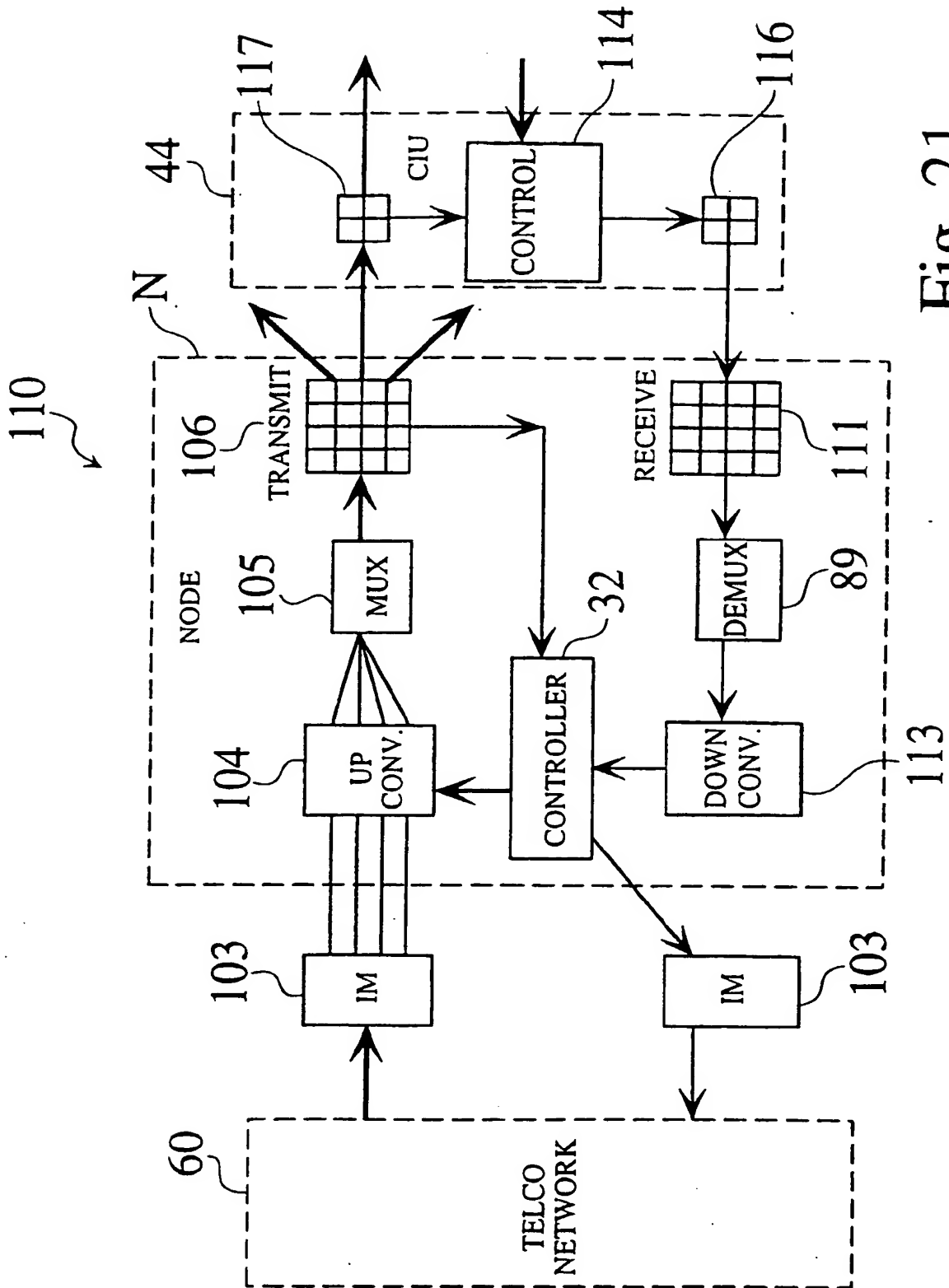


Fig. 21

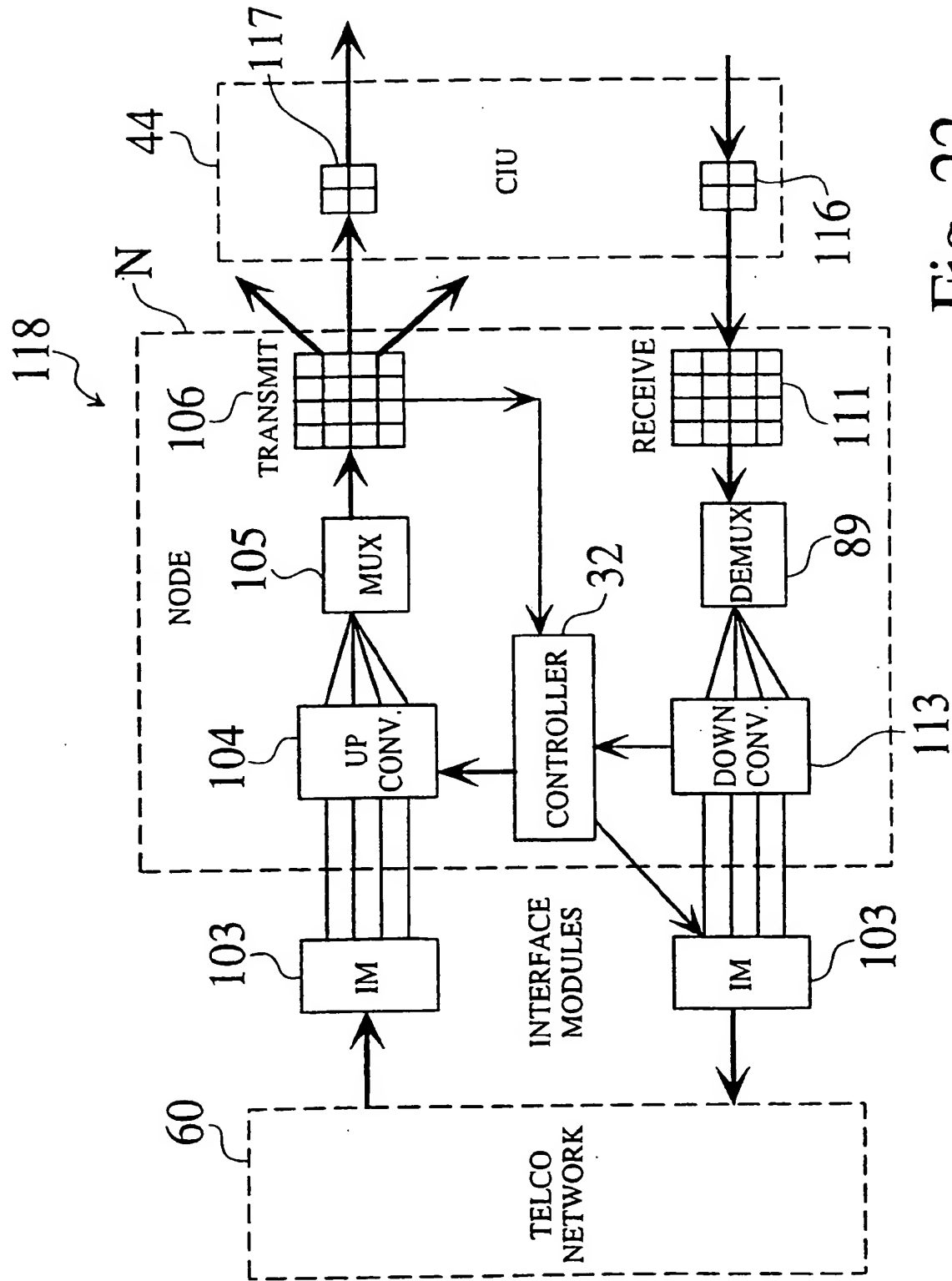
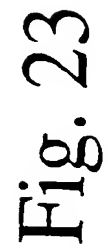


Fig. 22



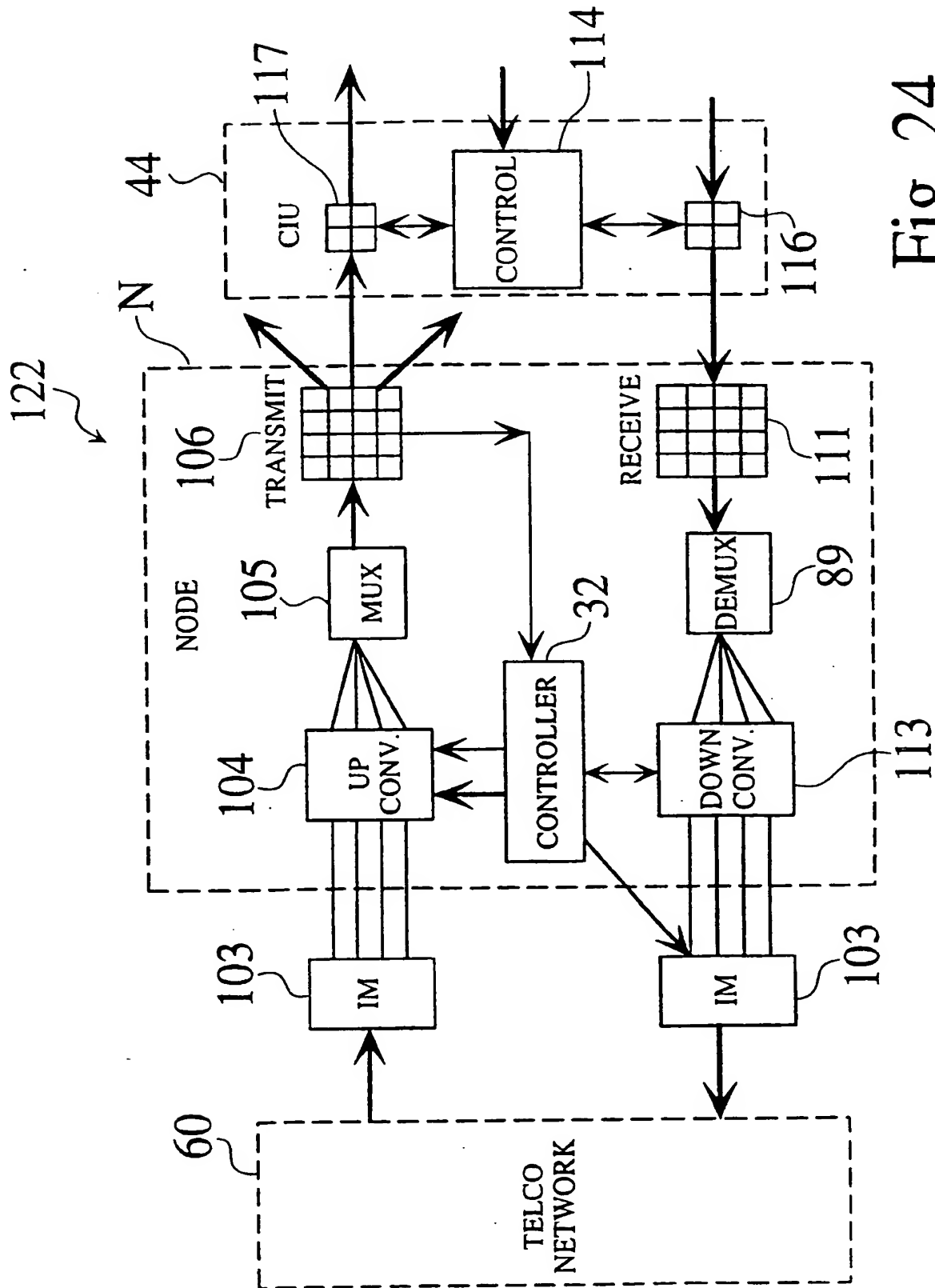
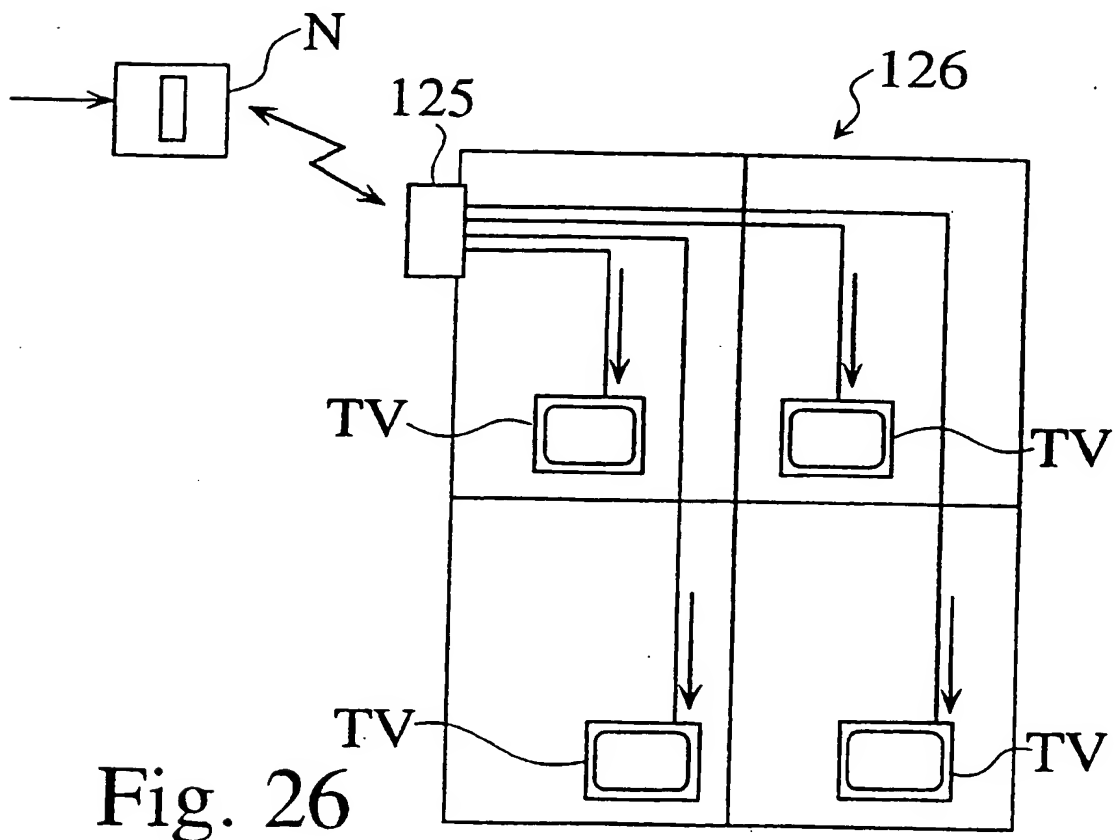
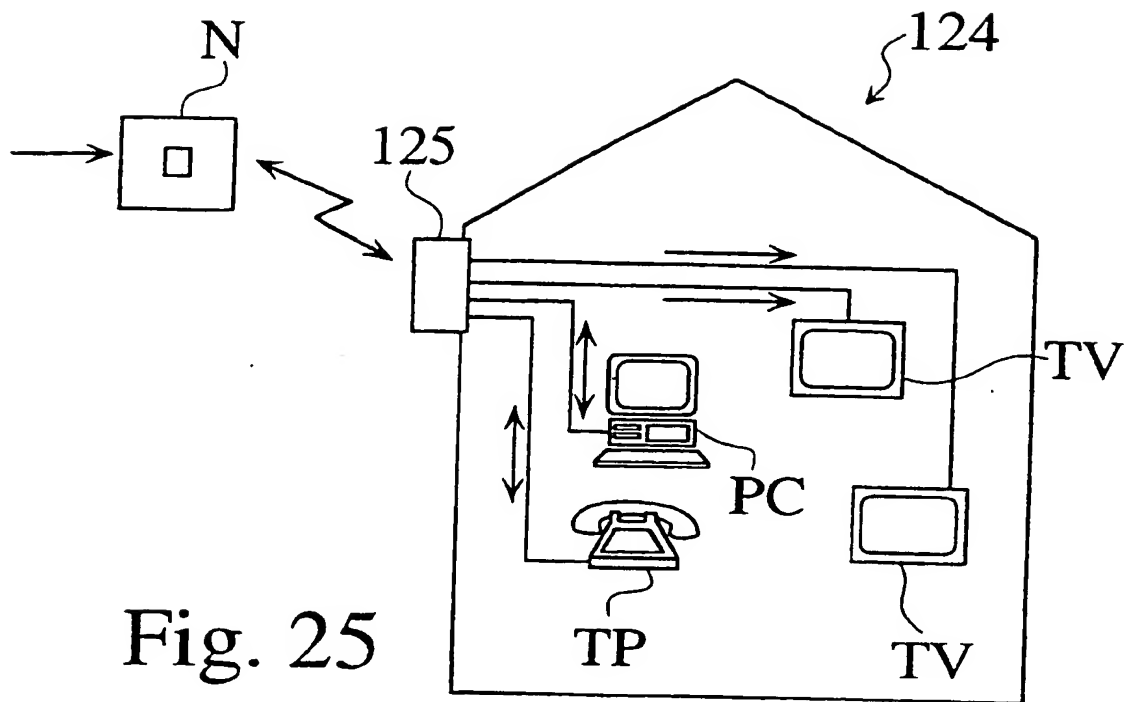


Fig. 24



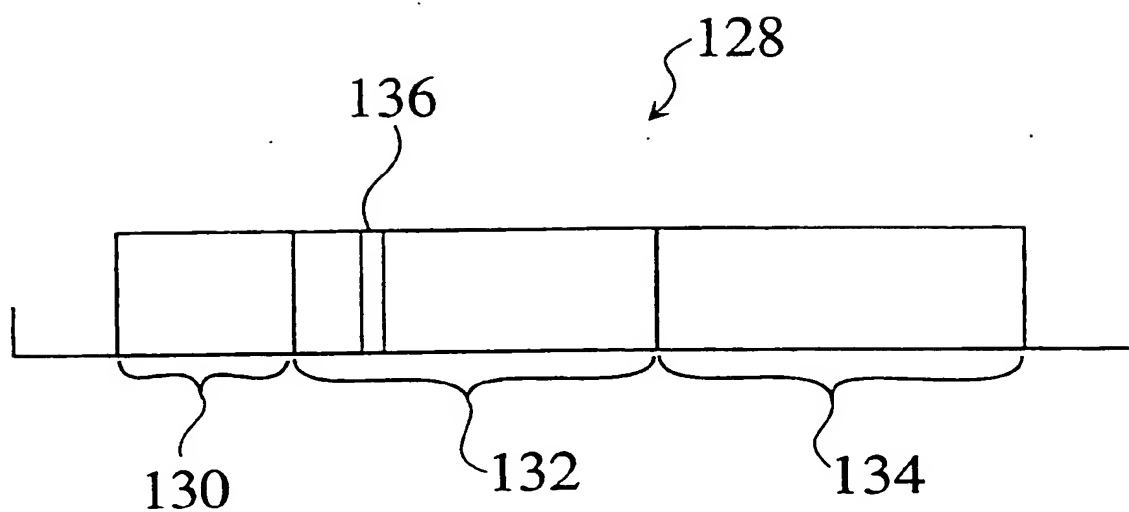


Fig. 27

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INTERDICT TABLE										
CHANNEL	2	3	4	5	6	.	.	25	26	.
ALLOWED	1	1	1	0	1	.	.	1	0	.

Fig. 28

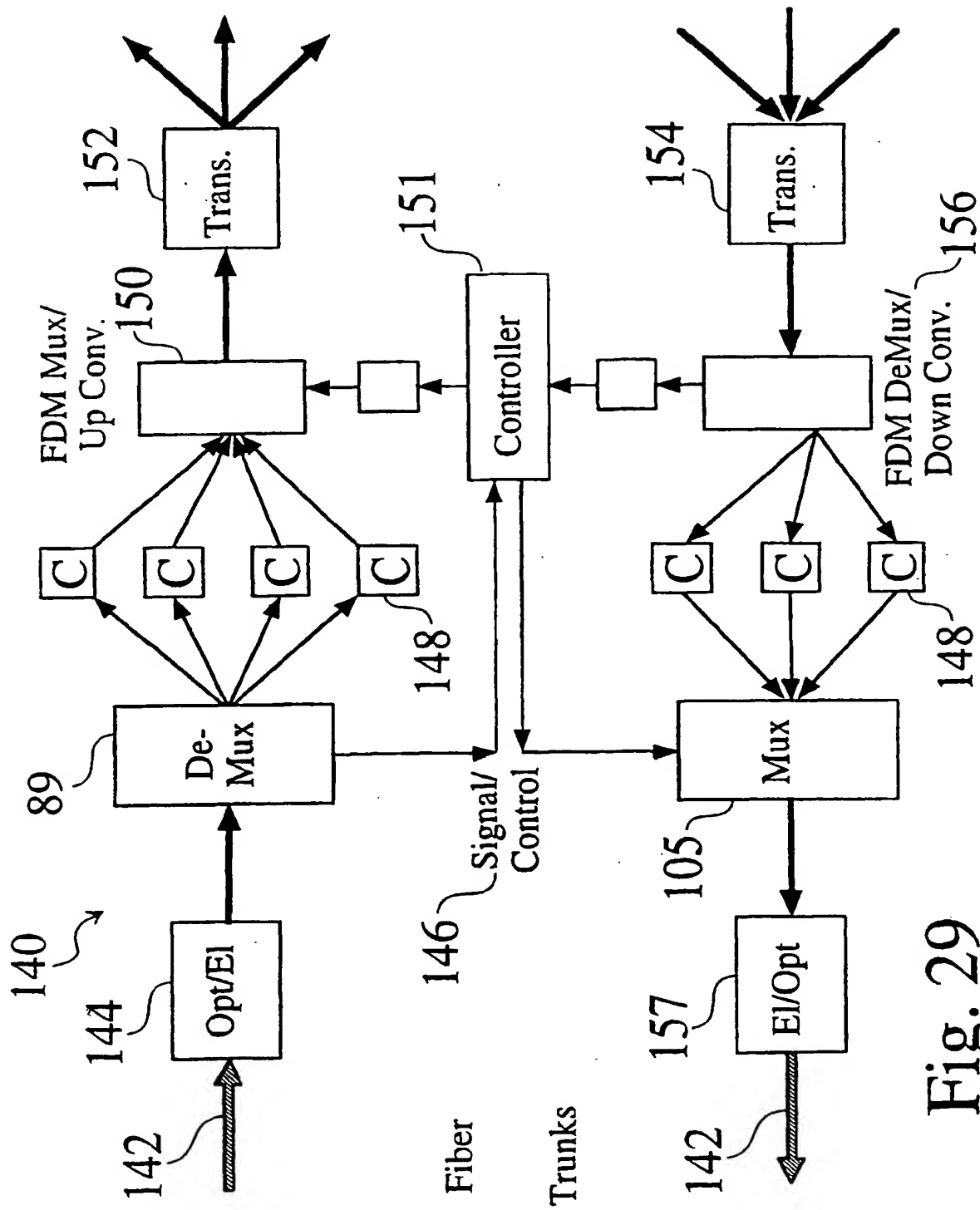


Fig. 29

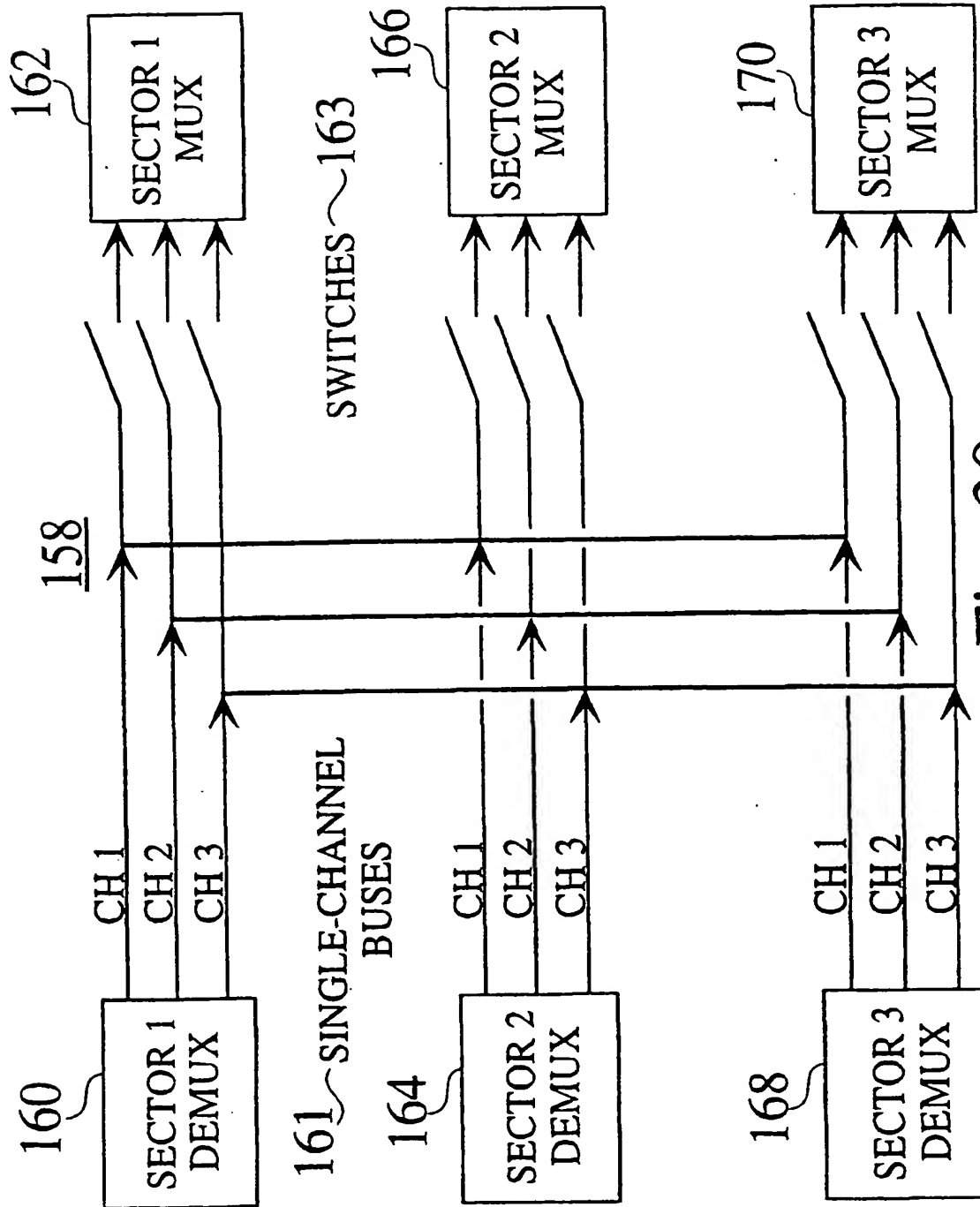


Fig. 30

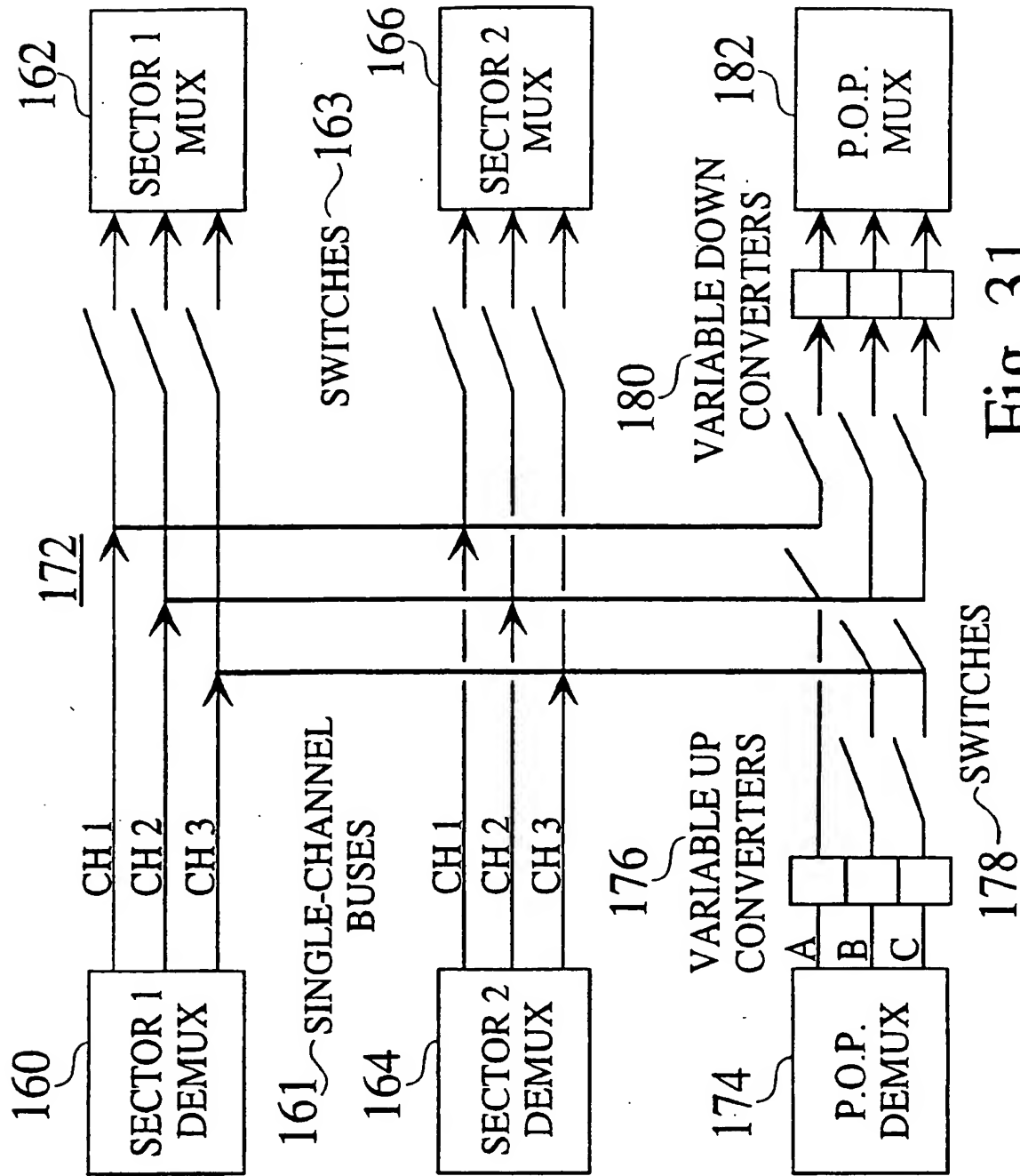


Fig. 31

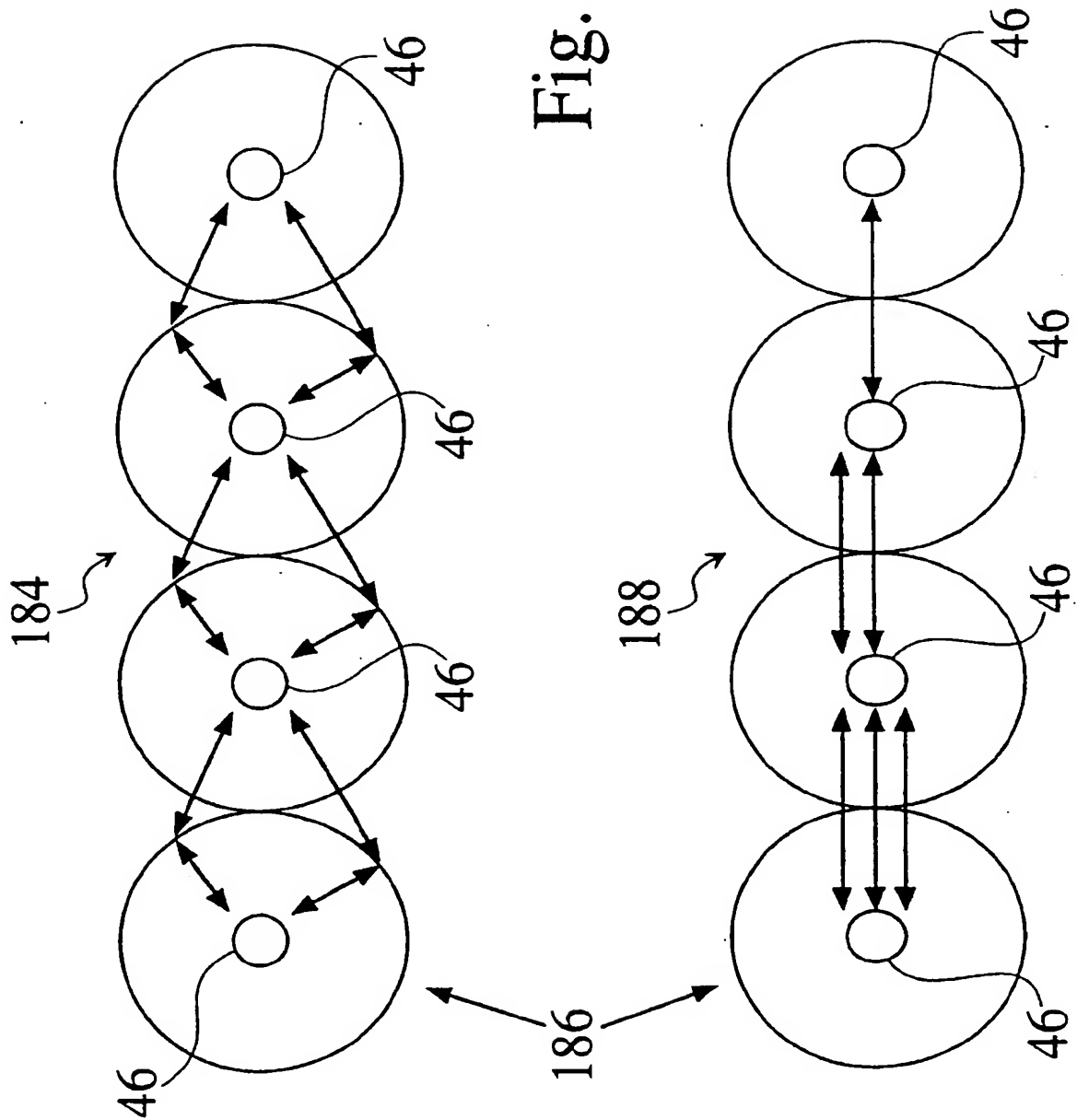


Fig. 32

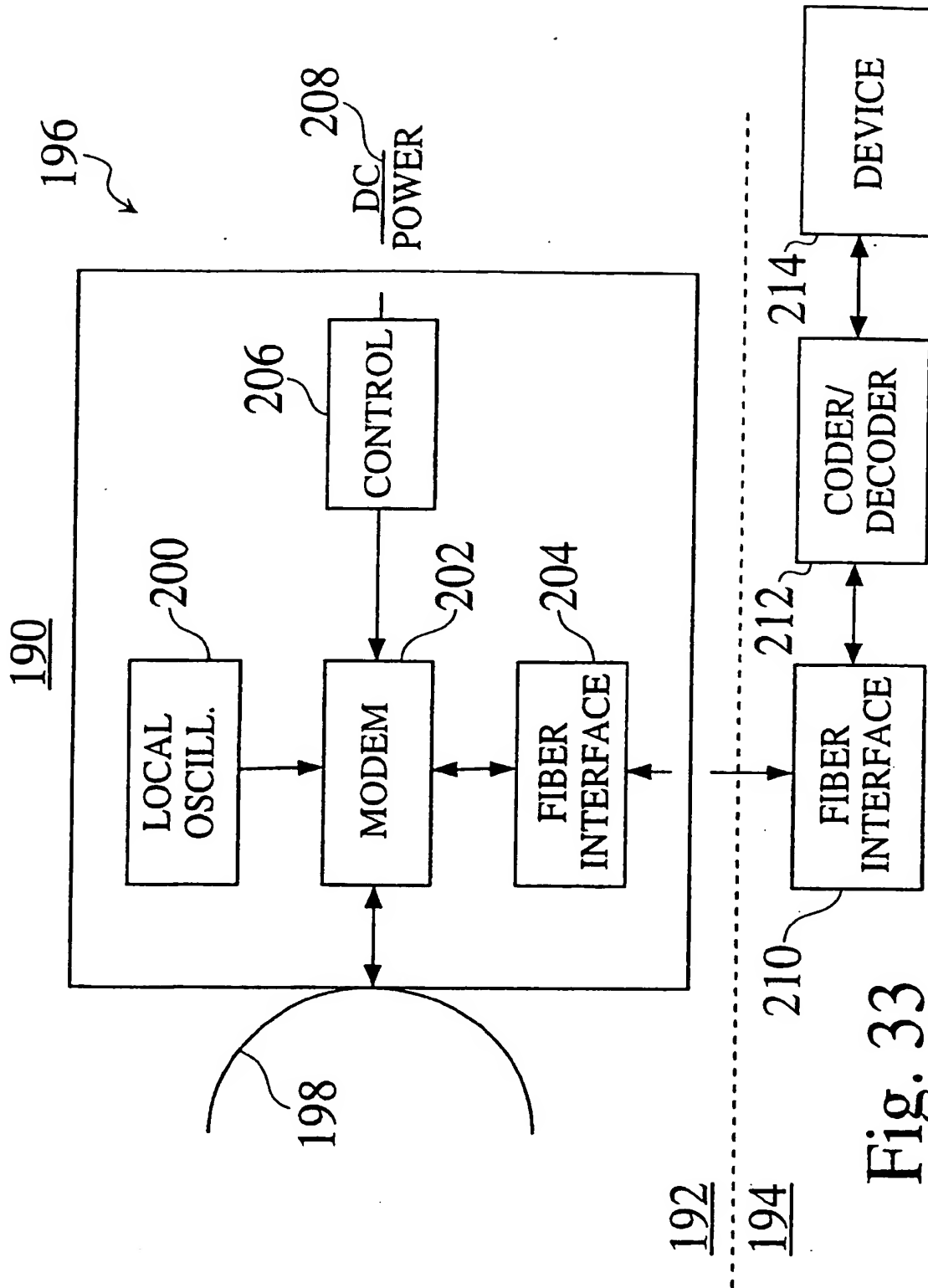
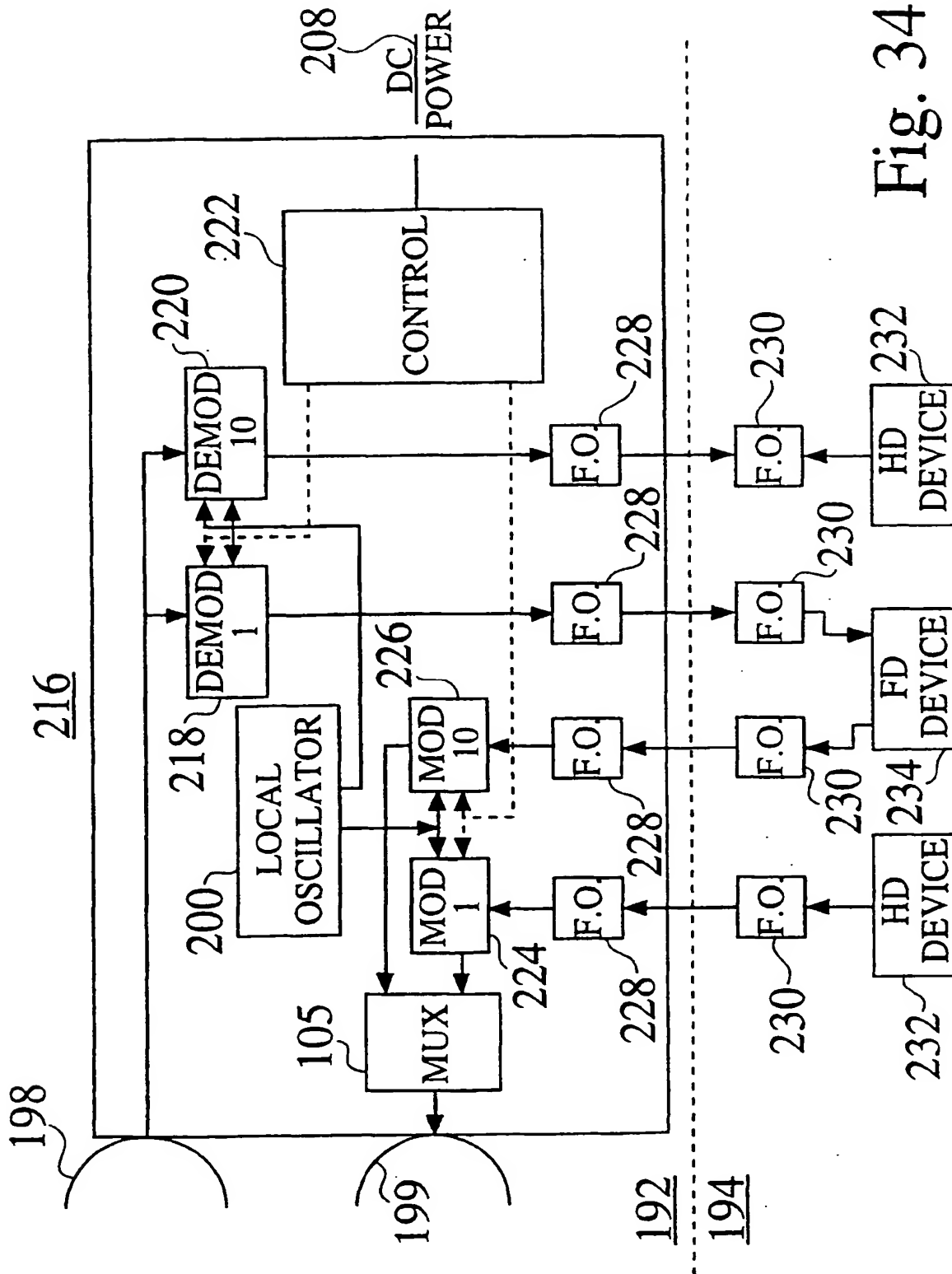
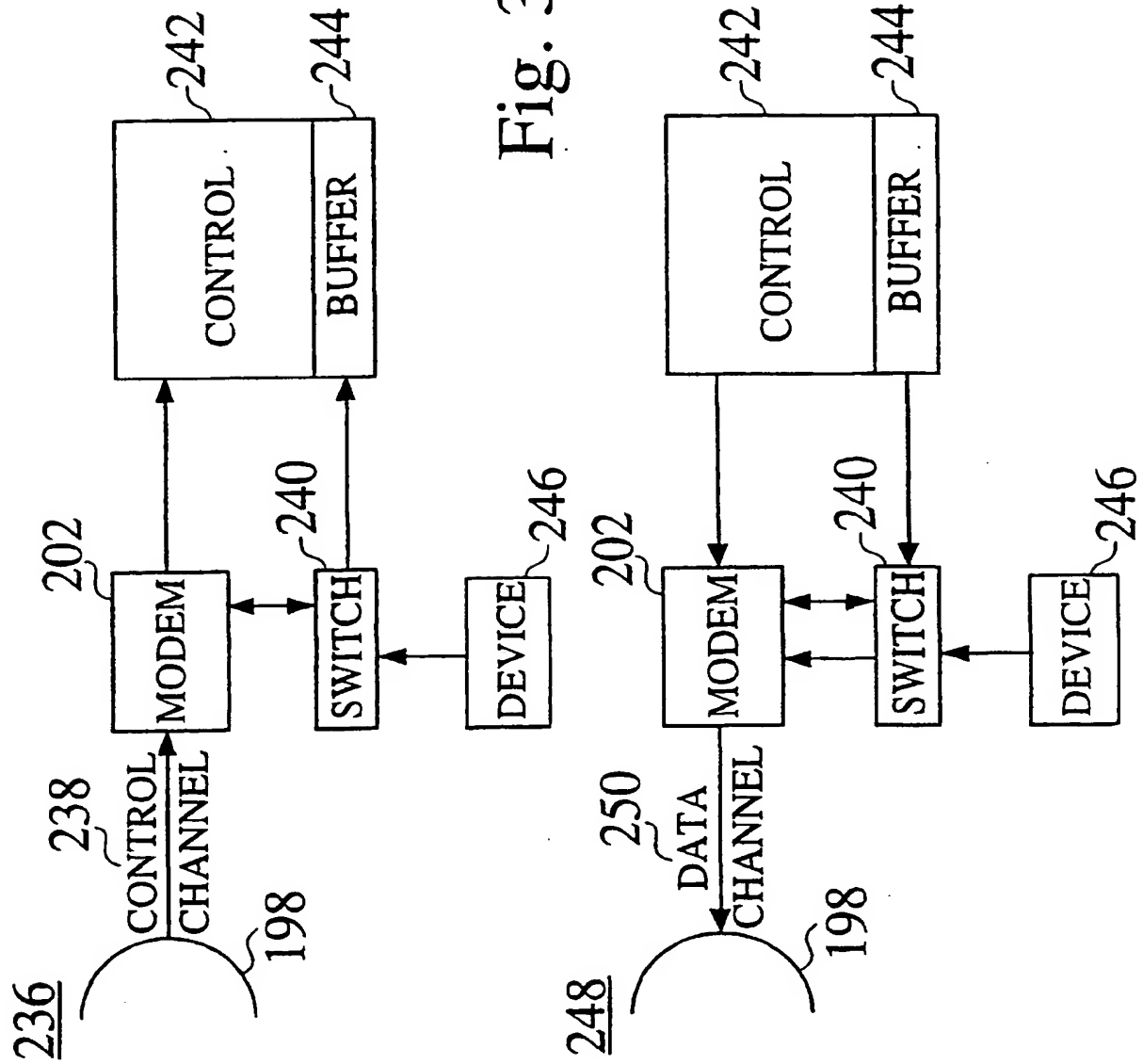


Fig. 33





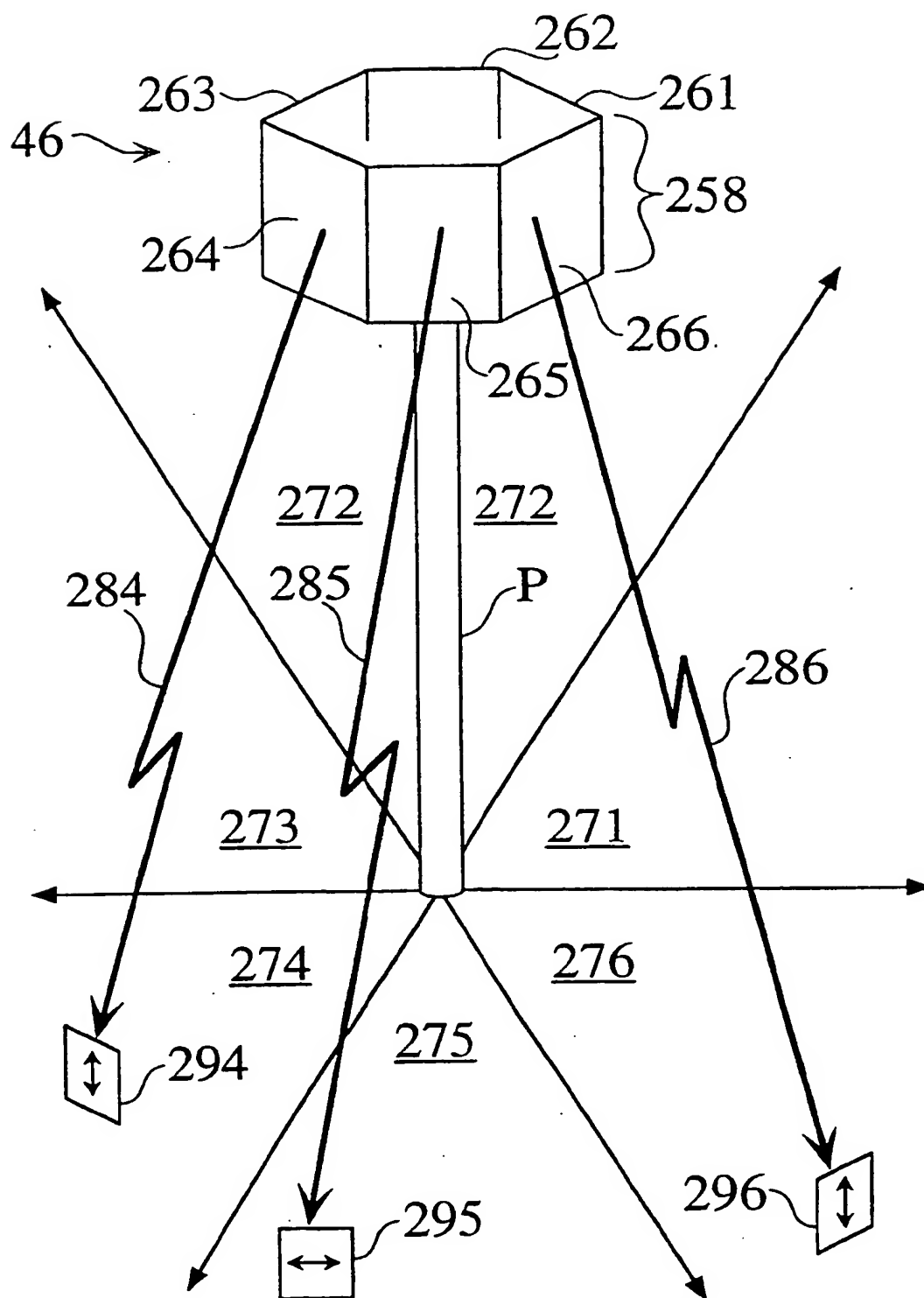
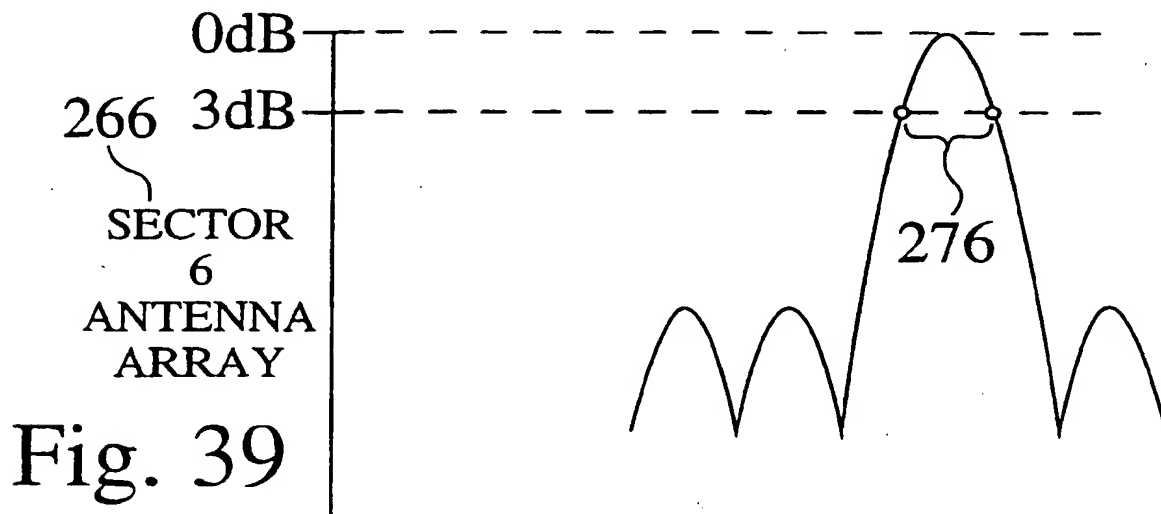
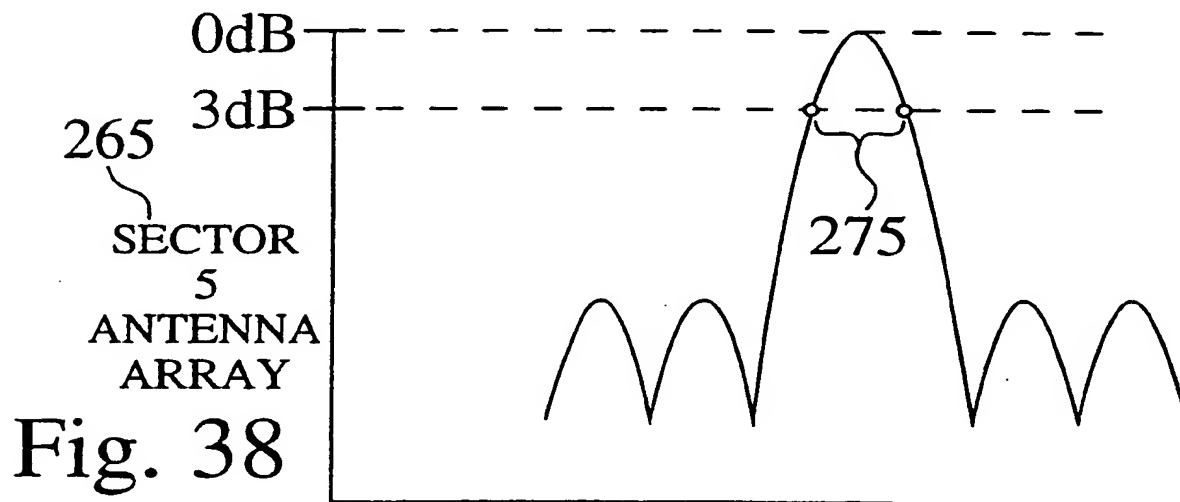
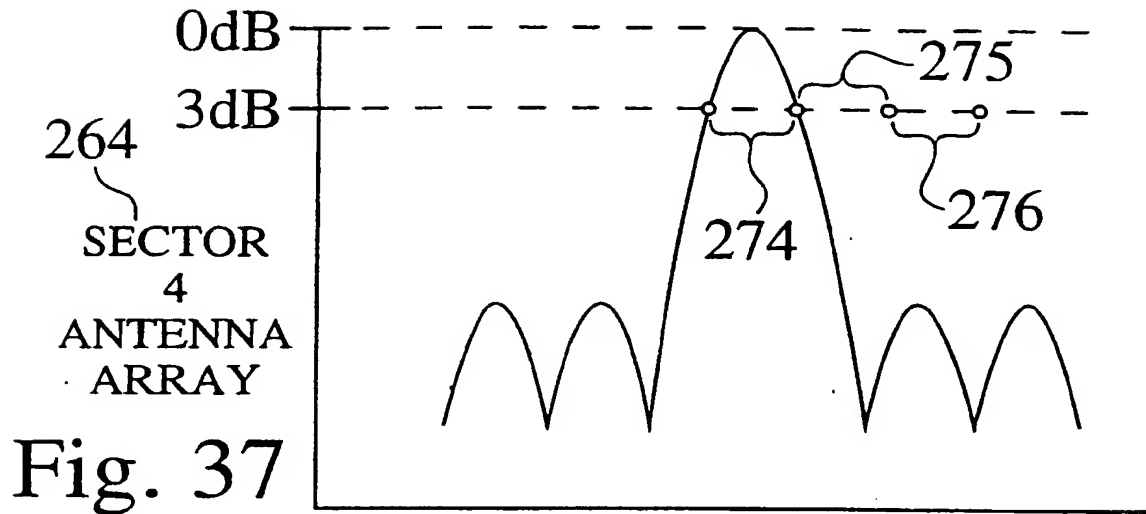
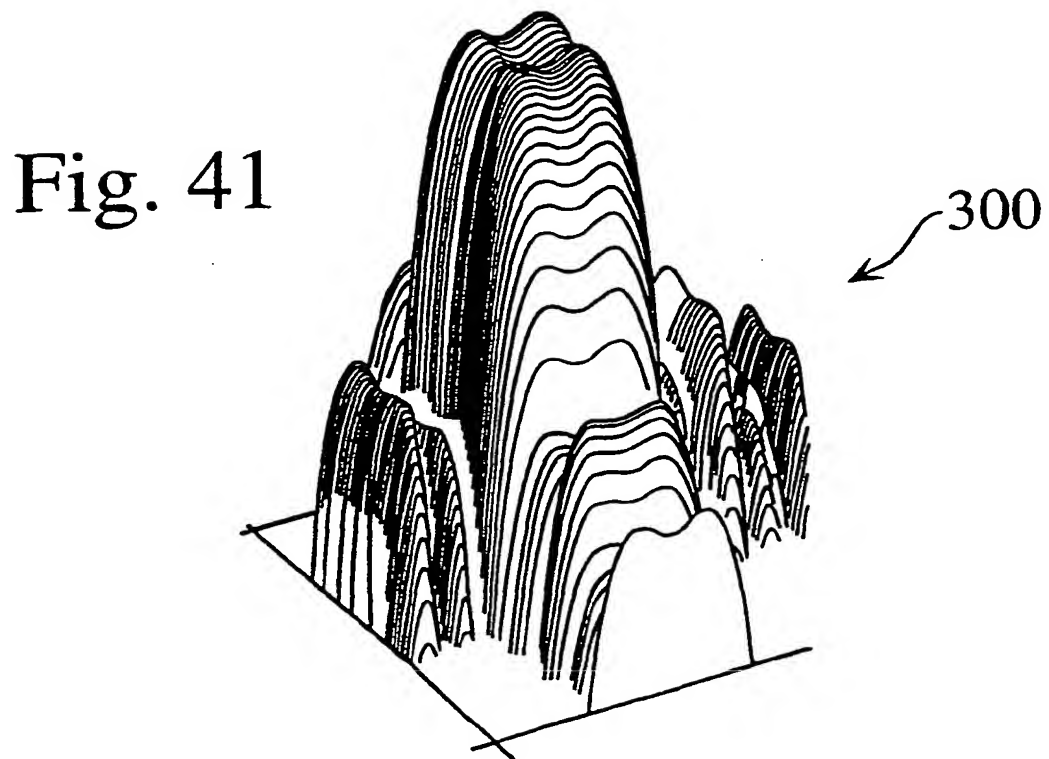
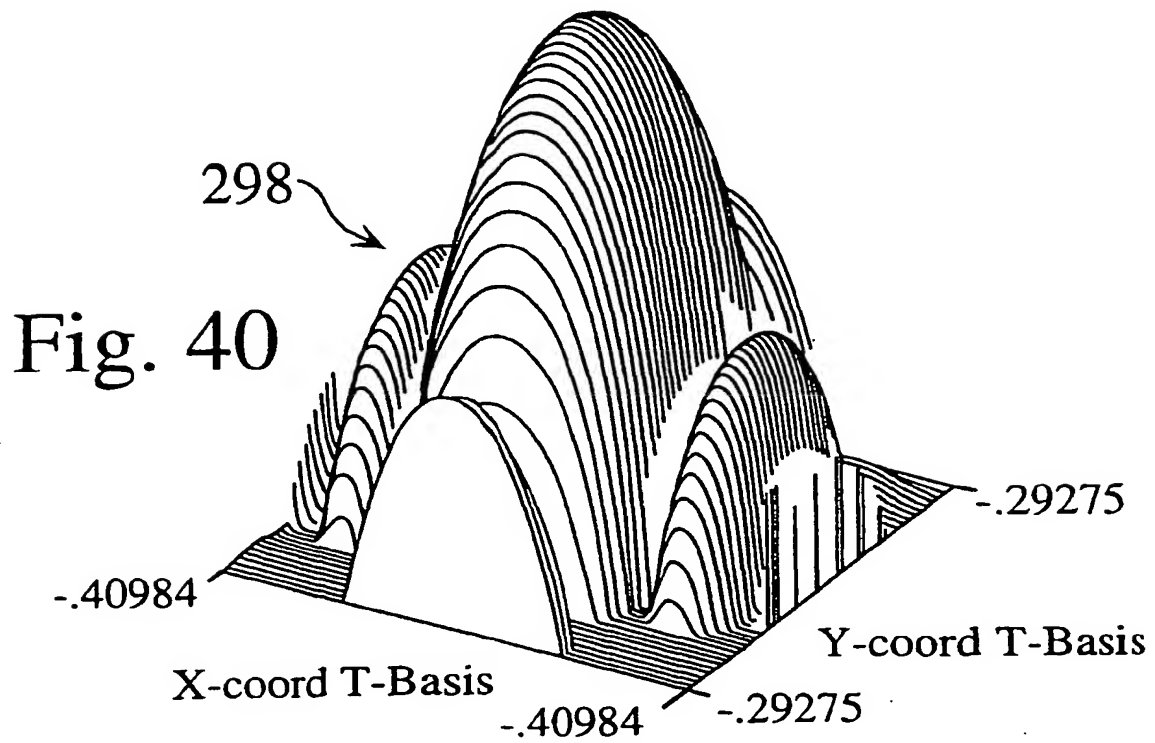
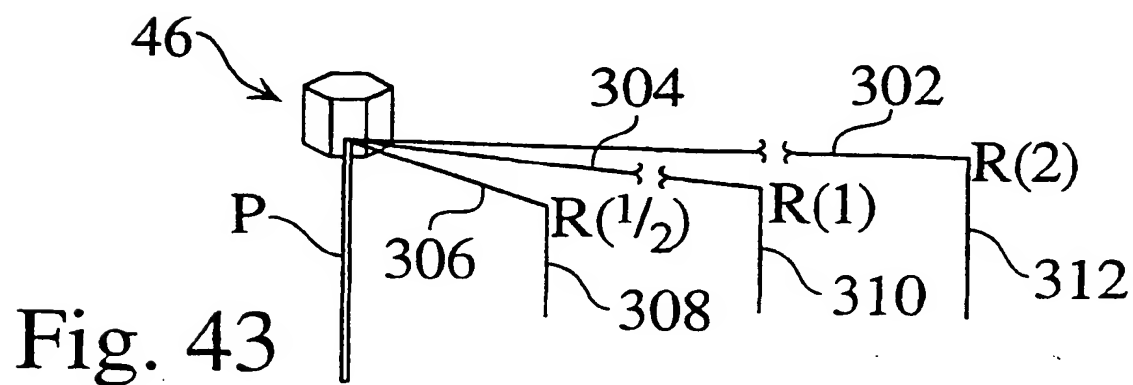
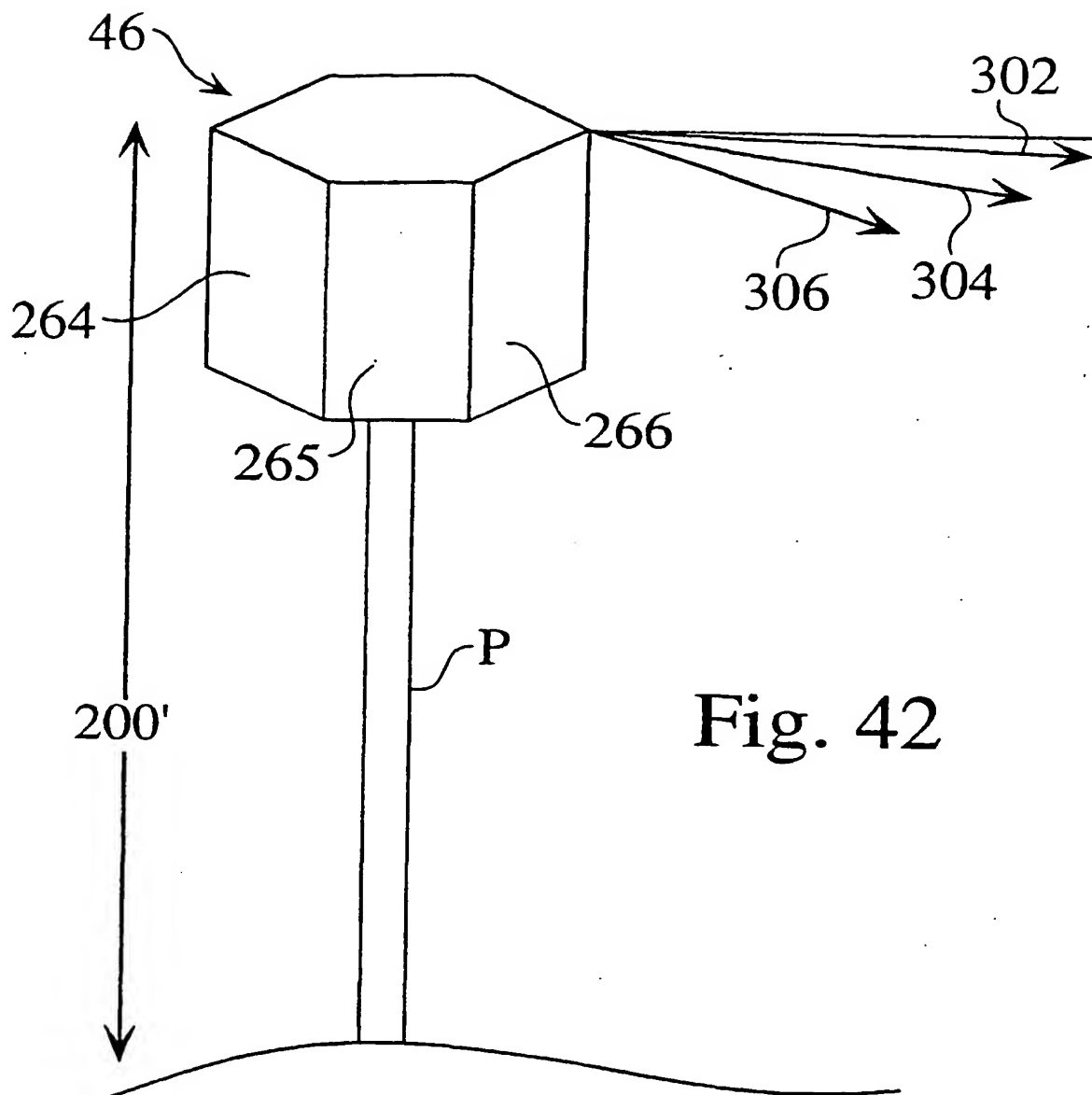


Fig. 36







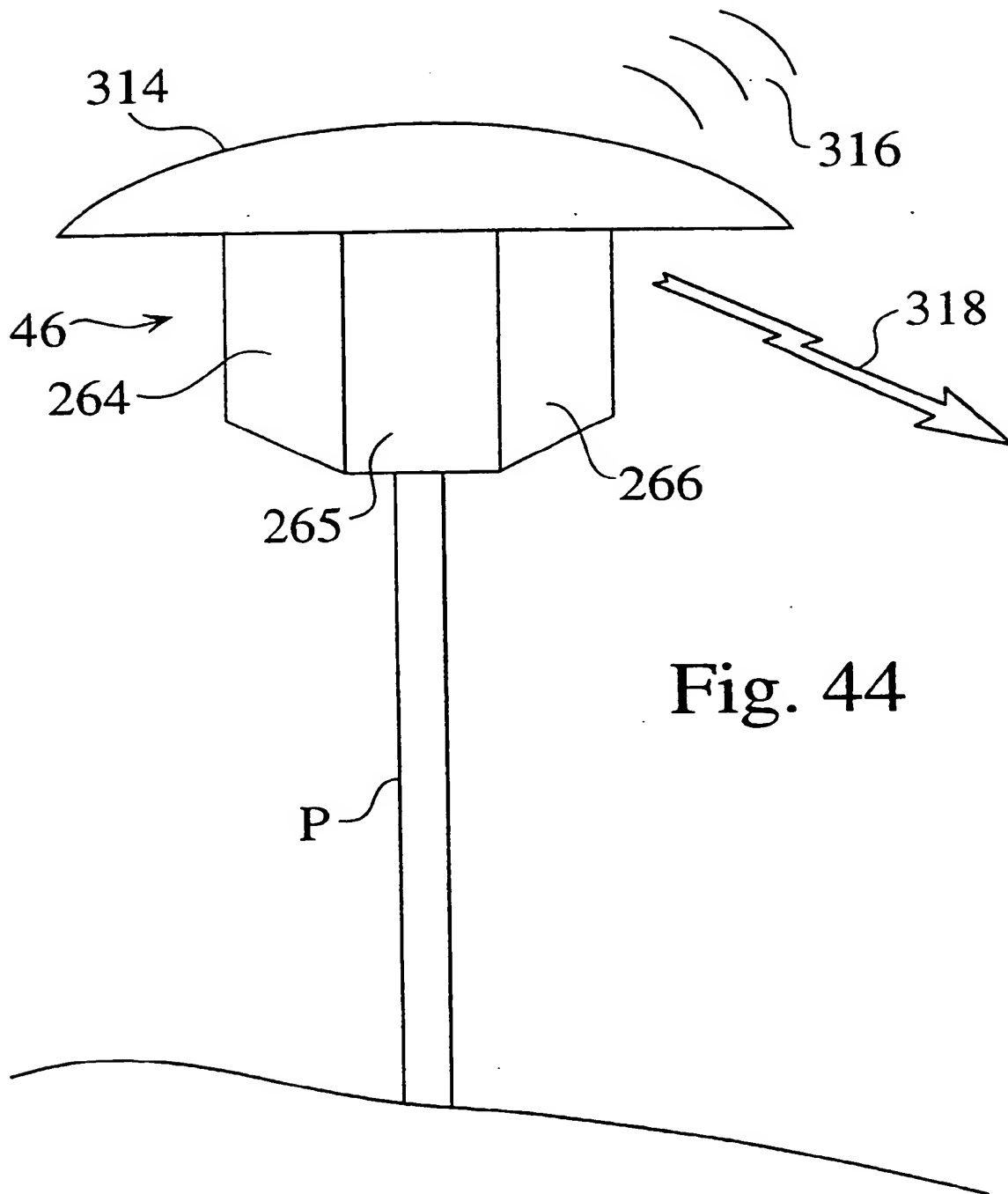


Fig. 44

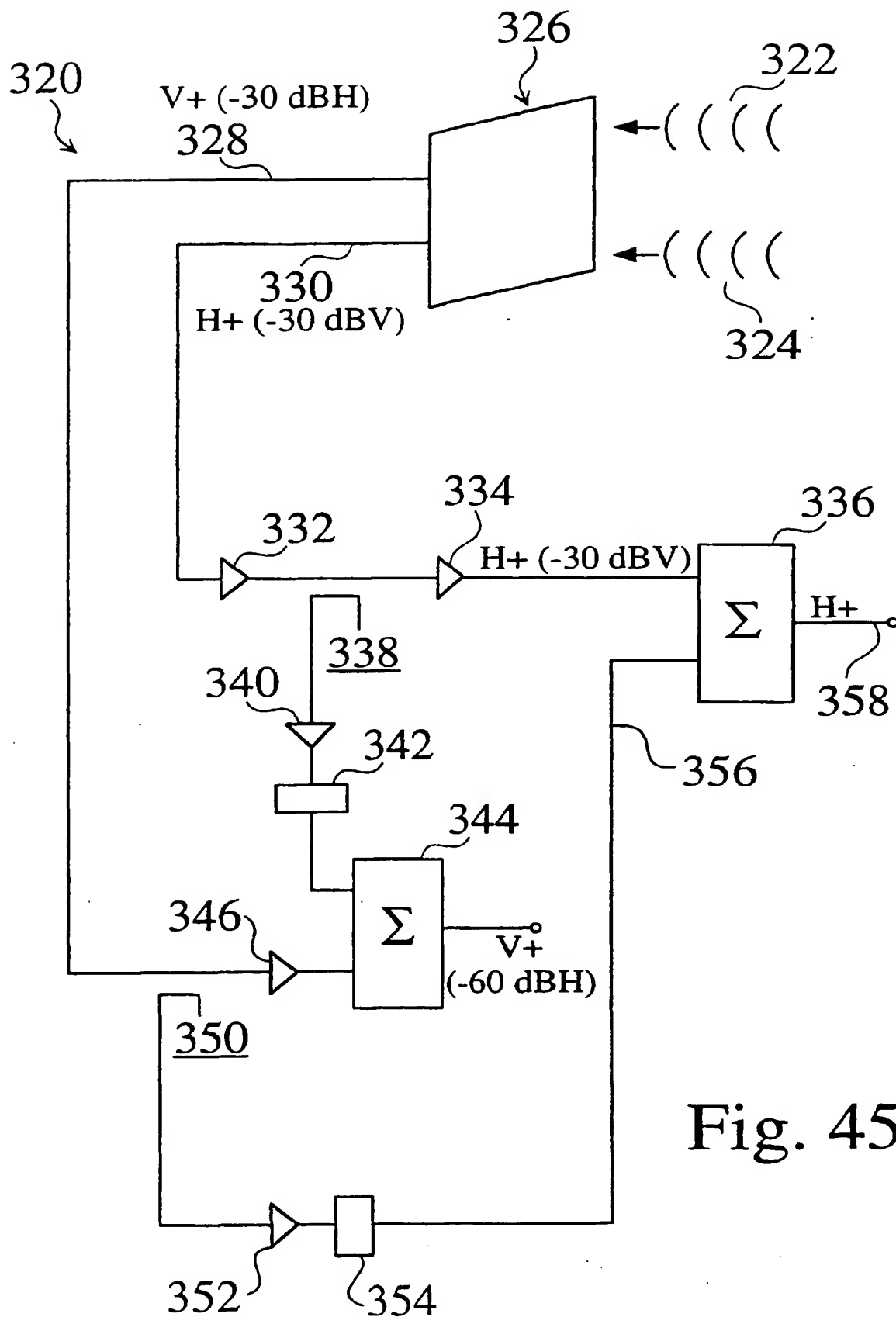


Fig. 45

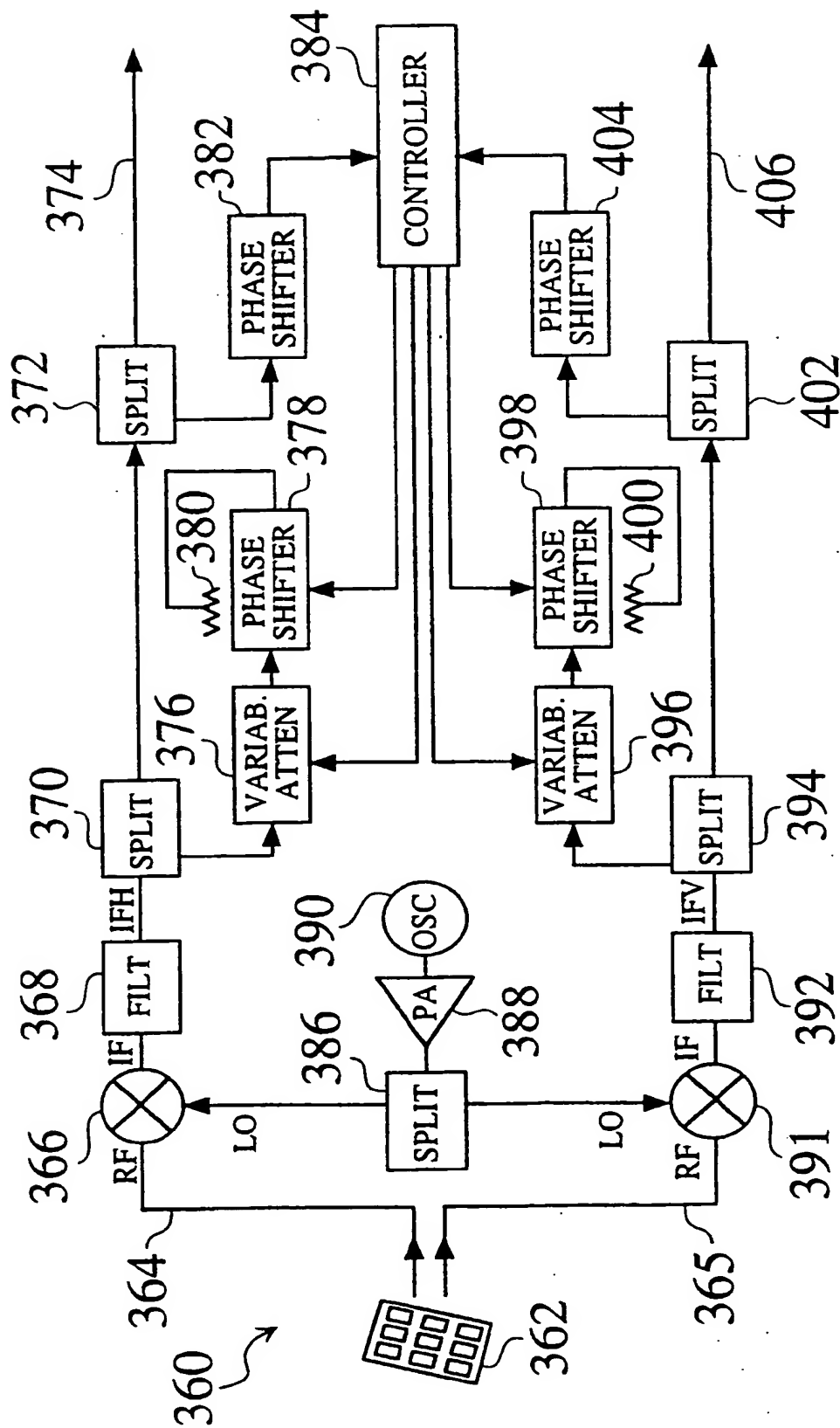


Fig. 46

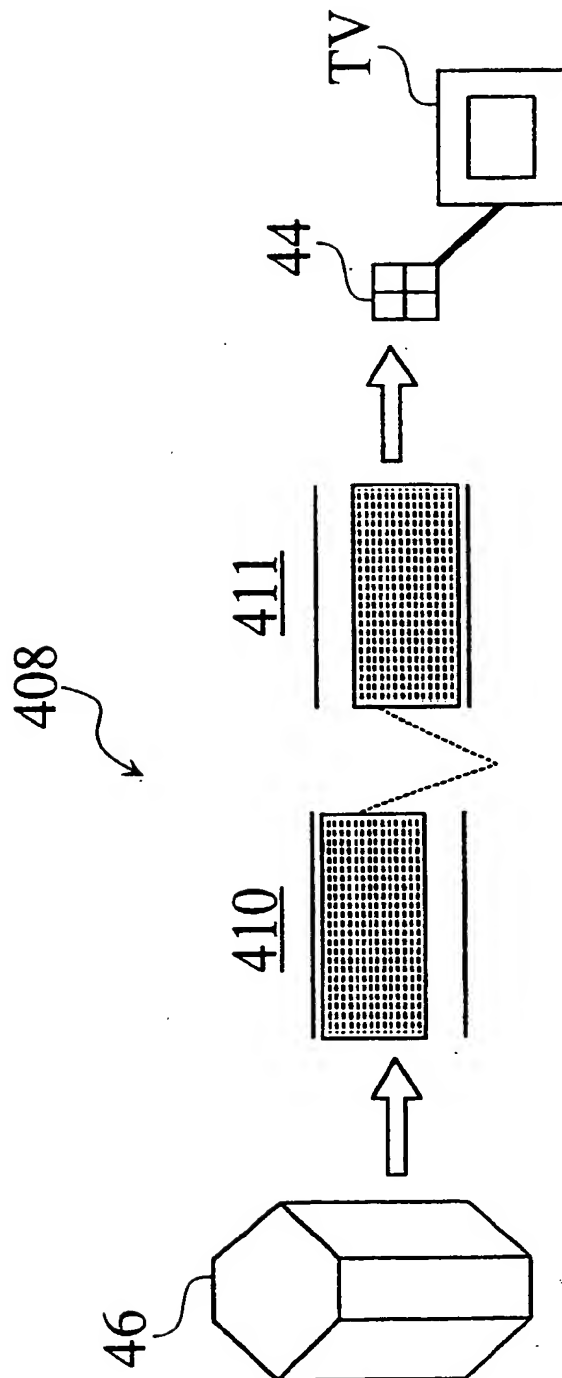
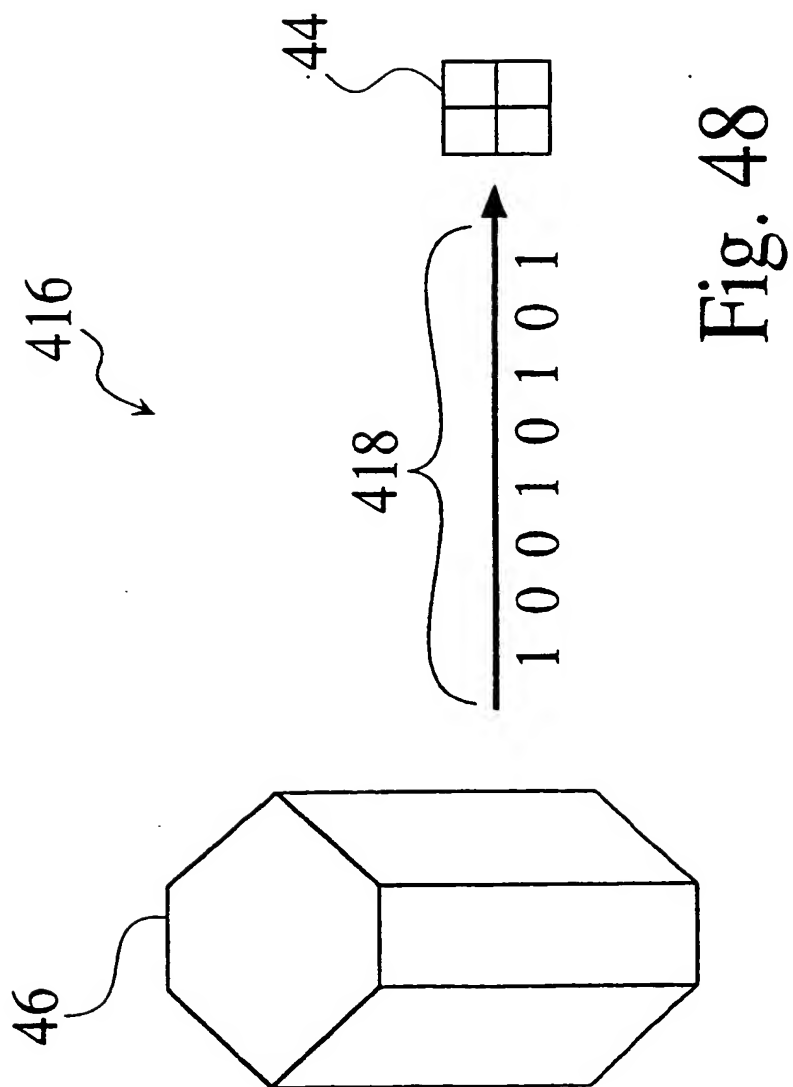


Fig. 47



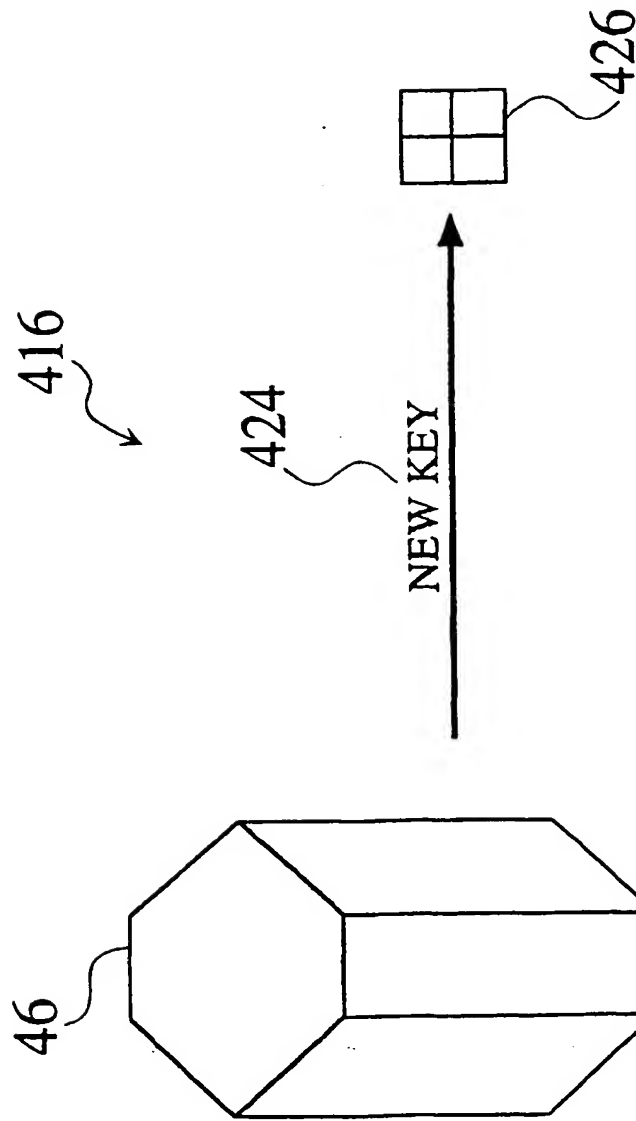


Fig. 49

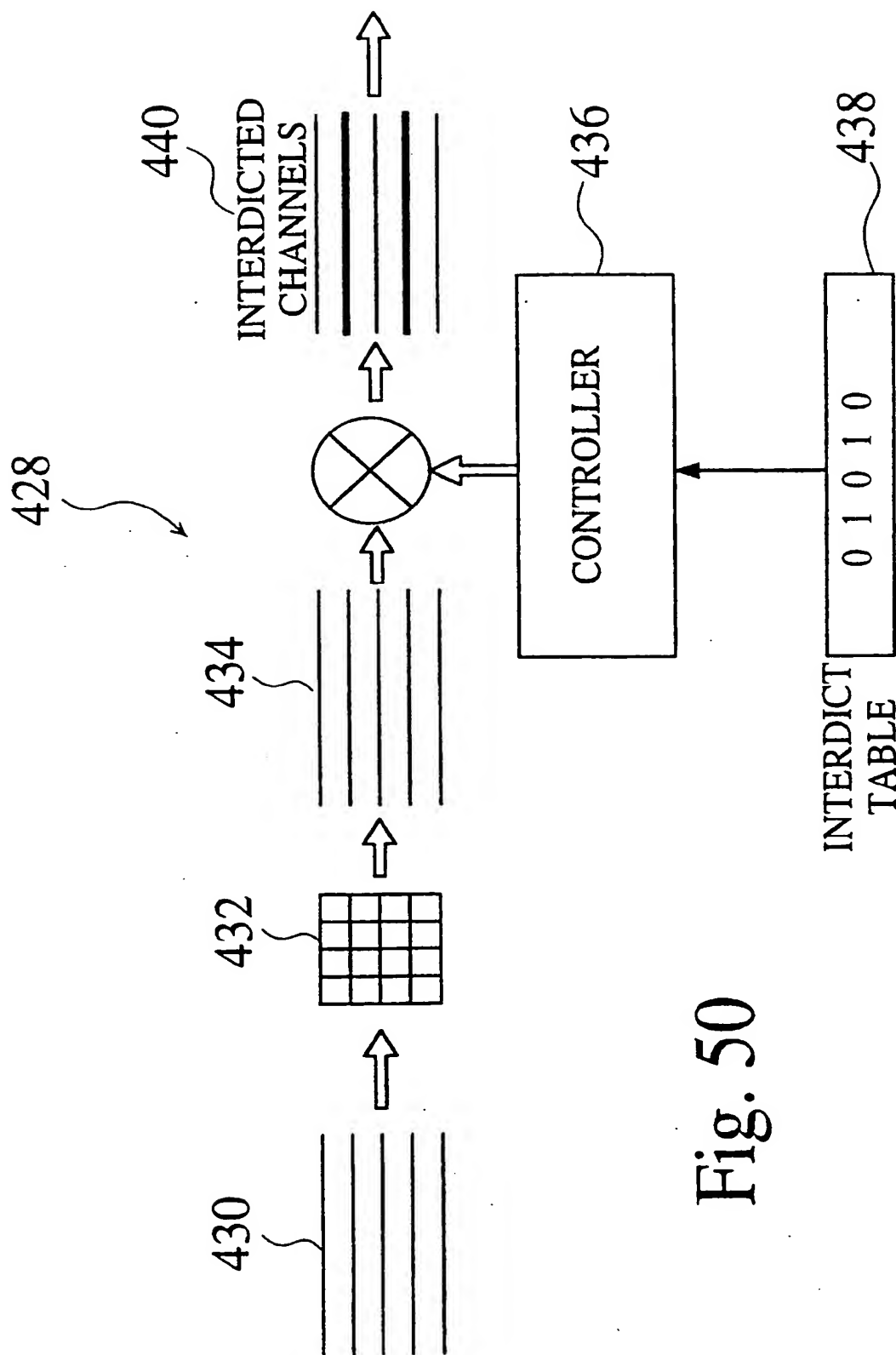
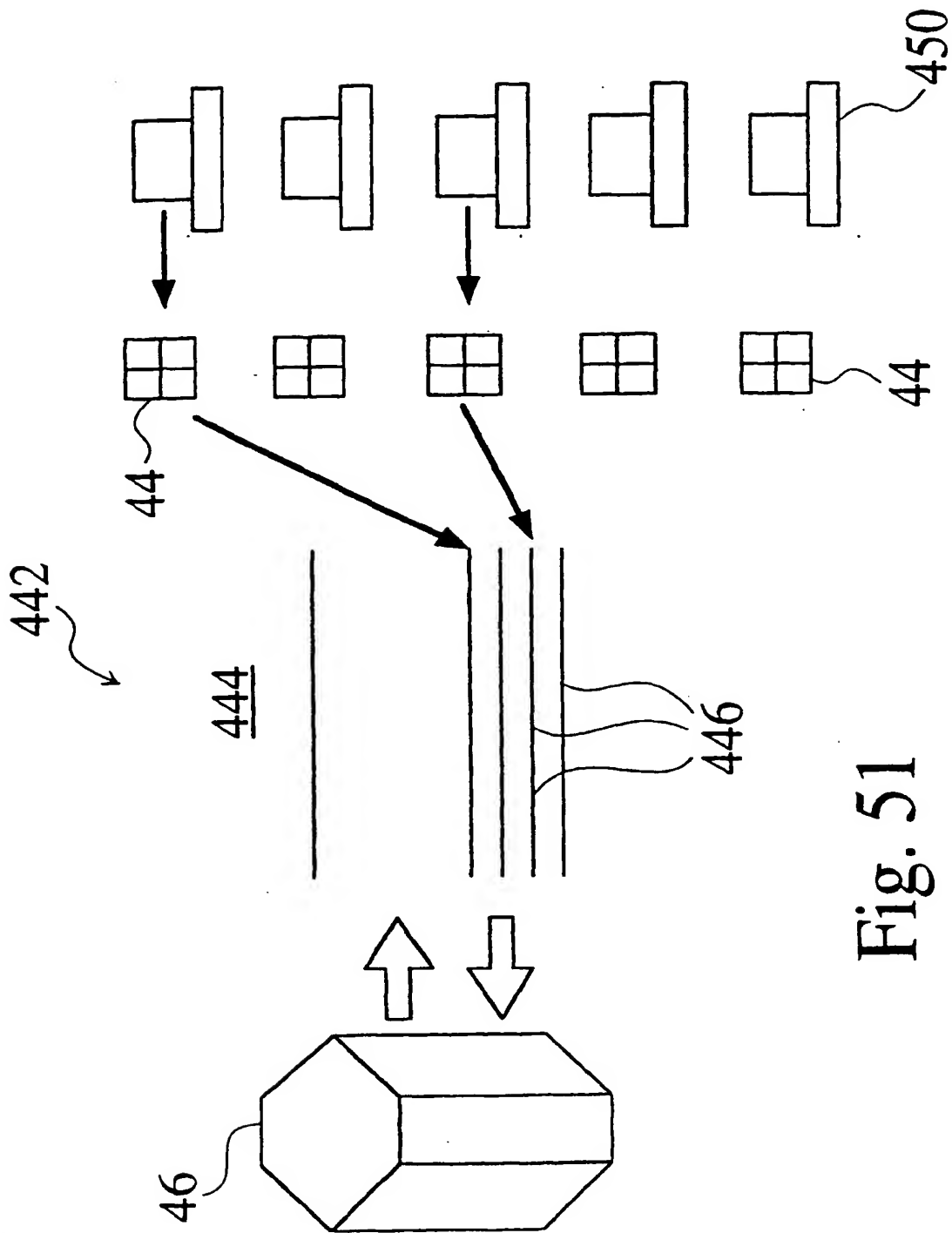
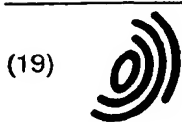


Fig. 50



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H04H 1/00

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(54) **Sectorized multi-function cellular radio communication system**

(57) A communications system (10A, 10B) comprises cells (11), each cell comprising a substantially centrally-located receiving and/or transmitting antenna member surrounded by a plurality of substantially sector-shaped regions (12, 14, 38, 40) extending out to the edge of the cell from the antenna member, the antenna member comprising a plurality of circumferentially distributed directional antenna elements (15A, 17A, 15B, 17B), each antenna element being arranged to communicate only with receivers (20, 22, 28, 30) located within a single one of said sector-shaped regions, the sector angles of the sector-shaped regions (12, 14, 38, 40) lying within the range 2 degrees to 15 degrees.

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European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 11 8162

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	WO 92 02996 A (INVENTAHL AB) 20 February 1992 (1992-02-20) * page 8, line 28 - page 9, line 6 * * page 49, line 7 - line 12 * * page 11, line 4 - page 13, line 11 *	1,2,4-9, 11,12, 15,16	H04Q7/36 H04Q7/20 H04H1/00
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A	GB 2 261 575 A (CSIR) 19 May 1993 (1993-05-19)		
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			H04Q H01Q
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 3 April 2000	Examiner Janysek, J-M
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03-04-2000

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